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The disposition effect and underreaction to private information☆

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ABSTRACT

We examine the role of the disposition effect in market efficiency following the arrival of private signals to a small group of informed traders. Subjects trade an ambiguous asset via a computer-based double auction. Using a $2 \times 2 \times 2$ design, we endow two types of signal, i.e., positive vs. negative, to informed traders with two different levels of the disposition effect, i.e., high vs. low, that are measured in two domains, i.e., gain vs. loss. We find that (1) the disposition effect measured in the gain domain has qualitatively different implications from the disposition effect measured in the loss domain; (2) following a favorable signal, informed traders with high disposition effect levels are more likely to sell and less likely to hold the asset while following an unfavorable signal, the opposite is true; (3) there is some evidence of stronger price underreaction in markets with informed traders with high disposition effect levels than in markets with informed traders with low disposition effect levels, but the effect is overall relatively weak; and finally and most importantly (4) the above results hold only when the sign of the signal matches the domain that the disposition effect levels of the informed traders are measured in.

1. Introduction

Aggregating diversified private information into prices is perhaps the most important function of markets (Hayek, 1945). Much effort has been devoted to the design of market mechanisms that could facilitate this function. However, markets are never perfectly efficient (Grossman and Stiglitz, 1980; Lo, 2004). Many factors could affect the speed and the scope with which private information is aggregated and transmitted to prices (see e.g., Bao et al., 2019; Barber and Odean, 2007; Bekaert et al., 2007; Chen et al., 2006; Garleanu and Heje, 2018; Merkley et al., 2017). Identifying those factors and examining their exact implications has been an important agenda for many researchers for decades. In this paper, we consider the disposition effect.

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The disposition effect, as first coined in Shefrin and Statman (1985), is defined as the tendency of investors to hold stocks with capital losses too long and to sell stocks with capital gains too soon. The disposition effect is perhaps "one of the most robust facts about the trading of individual investors" (Barberis and Xiong, 2009). It has been observed in stock markets (Chong, 2009; Hur et al., 2010; Odean, 1998), futures markets (Choe and Eom, 2009; Chou and Wang, 2011; Frino et al., 2004; Li and Yang, 2013), mutual fund markets (Cici, 2012; Frazzini, 2006; Singal and Xu, 2011), and experimental asset markets (Chang et al., 2016; Cueva et al., 2019; Da Costa Jr et al., 2013; Fischbacher et al., 2017; Frydman and Rangel, 2014; Hermann et al., 2019; Jiao, 2017; Pelster and Hofmann, 2018; Rau, 2015; Weber and Camerer, 1998; Weber and Welfens, 2007a, 2007b).

The possibility that the disposition effect could affect market efficiency has been well recognized (Frazzini, 2006; Grinblatt and Han, 2005; Kaustia, 2004; Weber and Welfens, 2007b). For a piece of private information that only a particular trader possesses to be incorporated into market prices, the trader must initiate trades. Following positive (or negative) information, there must be sufficient buying (or selling) activities to push up (or down) prices. However, traders exhibiting the disposition effect are likely to distort this process. They sell assets following capital gains and hold assets following capital losses. In a market in which many traders are affected by the disposition effect, together with limits of arbitrage (Shleifer and Vishny, 1997), those distortions might result in insufficient buying (or selling) pressure to push the price to the correct level. As a consequence, price underreaction and subsequent return momentum arises (Dacey and Zielonka, 2008; Frazzini, 2006), and markets become less efficient.

We experimentally investigate the role of the disposition effect in market efficiency following the arrival of private information to a small group of informed traders. Our contribution is mainly threefold. First, we make an explicit distinction between the disposition effect in bull markets, where most traders experience capital gains, and the disposition effect in bear markets, where most traders make losses. For this purpose, instead of using one general measure, as in Weber and Camerer (1998) and Weber and Welfens, 2007a, 2007b, we measure the disposition effect separately in the gain domain and the loss domain. Our measurement is built on prospect theory, arguably the most popular explanation of the disposition effect. Traders behaving consistently with prospect theory use the purchasing price of an asset as the reference point and code prices above it as gains and below it as losses. The S-shaped value function predicts a higher propensity to sell the asset with gains due to risk aversion in the gain domain and a stronger willingness to hold the asset with losses due to risk seeking in the loss domain, resulting a trading pattern that is consistent with the disposition effect. If prospect theory is indeed a driving force behind the disposition effect, in bull (or bear) markets where most traders have capital gains (or losses), only the disposition effect driven by the value function in the gain (or loss) domain is relevant. After all, decisions to sell winning stocks and hold or buy losing stocks are, from a behavioral point of view, fundamentally different. There is no reason to believe that traders affected by the disposition effect in bull markets are the same ones affected in bear markets. If the disposition effect affects different populations in bear markets than in bull markets, it might result in different market dynamics. Indeed, on the individual level investors "exhibiting a strong tendency to quit winning investments quickly are not necessarily the same investors who stick to their losing ones" (Weber and Welfens, 2007a, pp. 25); on the aggregate level, prices underreact strongly after a positive shock, while prices underreaction is much less pronounced following negative shocks (Weber, Welfens, 2007). Further evidence can be found in Frazzini (2006) and Weber and Welfens (2008). Consequently, it is important to distinguish the disposition effect in the gain domain and the loss domain.

Second, we consider the relationship between the disposition effect and market efficiency using private instead of public signals. The link between the disposition effect and price underreaction has been shown in, among others, Grinblatt and Han (2005), Frazzini (2006) and Weber, Welfens, 2007. The focus of those studies has been on the arrival of public information. While those studies provide important insights on the existence and implications of the disposition effect, they neglect some important points. First, as we point out in the beginning of the introduction, a primary function of markets is to aggregate diversified private information rather than public information. Hence, it is essential to know the role of the disposition effect in the translation of private information to market prices. Second, in studies relying on public signals, it is not entirely clear whether and how the disposition effect directly affects market efficiency. Following public signals, market prices generally need some time to fully reflect new information, instead of immediately jumping to the new equilibrium level, as predicted by the efficient market hypothesis. However, it is unclear what exact role the disposition effect plays in this process. The disposition effect is not defined by the ability to absorb information, and traders affected by the disposition effect might process information and adjust their trading prices as quickly as other traders. Therefore, the underreaction of market prices to public signals per se might come from factors other than the disposition effect. The results found in works such as Weber and Camerer (1998), Weber and Welfens, 2007a, 2007b might merely reflect a correlation of those factors with the disposition effect. With private information, market prices adjust slowly, and the disposition effect has a clear role in this process. Moreover, different types of signals could imply different trading dynamics. Unlike in the case of public information, the informed traders have a distinct informational advantage over the uninformed traders. They might construct trading strategies that could hide their information and exploit the information advantage for as long as possible (e.g., Buffa, 2013). Those trading strategies might lead to a potentially stronger underreaction when signals are private rather than public. It is interesting to see if and to what extent the disposition effect plays a role in those dynamics.

Finally, our investigation relies on experimental asset markets instead of empirical data. An experimental approach, in contrast to empirical methods, provides us with full control over the fundamental value of the asset, the information structure of signals, and the behavioral trait – the level of the disposition effect – of the informed traders receiving signals. Those tight controls allow us to directly test the role of the disposition effect in market efficiency without having to worry about

other confounding factors, such as mean reversion in beliefs, portfolio re-balancing, and trading costs. Furthermore, by examining detailed micro-structure trading data, we are able to get a comprehensive view of the whole translation process from signals to prices and to pinpoint the steps where things go wrong.

Our experiment consists of two main parts. In the first part, we measure the level of the disposition effect separately in the gain and loss domains using a novel method. The basic task in our measurement method consists of playing an ambiguous lottery for a maximum of four rounds. The ambiguous lottery is the same in all rounds and offers either a gain or loss of 400 Experimental Currency Units (hereafter ECU). The task ends once subjects decide not to play the lottery. Consistent with the empirical definition of the disposition effect, subjects who experience a gain in playing a lottery should become less likely to proceed to next rounds, while subjects who experience a loss in playing a lottery should become more likely to proceed to next rounds. To more accurately and effectively measure the level of the disposition effect, we manipulate the outcomes of the ambiguous lottery in two out of six tasks, such that subjects face four continuous gains in one manipulated task and face four continuous losses in the other, if subjects play to the end.

In the second part of the experiment, nine subjects compose a market and trade an asset via a computer-based double auction. The final value of the asset depends on the color of a randomly drawn ball from an ambiguous bowl. It is common knowledge that three of the nine subjects are informed traders. Each market trading is divided into two phases. Subjects trade the asset for two minutes in the first phase, then three subjects – informed traders – receive the same private signal, and trading continues for another two minutes. Our central focus is on the implications of the informed traders disposition effect levels on their individual trading behavior and aggregate market performance. For this purpose, we appoint informed traders according to their levels of the disposition effect; i.e., informed traders are three subjects either with the highest or the lowest levels of the disposition effect in a market. We consider both the disposition effect in the gain domain and that in the loss domain. The signals that informed traders receive are of two types. A positive signal excludes a bad state and implies the value of the asset is more likely to be high, whereas a negative signal excludes a good state, and thus the value of the asset is more likely to be low. In the experiment, we deliberately construct markets in which the sign of the signals (positive/negative) either matches or does not match the domain in which the levels of the disposition effect are measured. This allows us to check whether the disposition effect measured in the two domains indeed has different implications. To cover the whole spectrum, we run eight treatments in total with a within-subject design so that we have: two levels (high/low) of the informed traders disposition effect levels $\times$ two domains (gain/loss) in which the disposition effect levels are measured $\times$ two types (positive/negative) of private signals.

Our results show that disposition effect levels measured in the two domains are not correlated, suggesting individuals exhibit higher levels of the disposition effect in bear markets than in bull markets. In line with the disposition effect, we find that informed traders with high disposition effect levels exhibit a significantly greater (or lower) willingness to hold the asset following a negative (or positive) signal than informed traders with low disposition effect levels. This willingness is evident both from the numbers and the prices of (submitted and accepted) bids and asks. Furthermore, the differences in the trading behavior result in substantially different asset holdings between informed traders with high and low disposition effect levels. At the aggregate market level, we observe significant underreaction following both types of private signals, and there is no indication that prices are approaching a new fundamental value within the trading round of the double auction market. We find some evidence that markets with informed traders with high (low) disposition effect levels experience stronger (weaker) price underreaction. This is true following both a positive and negative signal, although the difference is more obvious following a negative signal. Finally and most importantly, the above results hold only when the sign of private signals (positive/negative) matches the domain in which the disposition effect levels are measured.

The rest of the paper is structured as follows. Section 2 presents the experimental design, procedures and hypotheses. In Section 3, our results are presented and discussed. Finally, Section 4 concludes.

2. Experimental design

2.1. Measuring individual disposition effect levels

Our measure of individual disposition effect levels is based on prospect theory (Kahneman and Tversky, 1979). Specifically, in the basic task of our measurement method, subjects repeatedly face an ambiguous lottery which pays out either +400 ECU or -400 ECU for a maximum of four rounds.[1] At the beginning of each round, subjects need to decide whether or not to play the lottery. The task ends once subjects decide not to play the lottery in a round. The fundamental idea of our measurement is that subjects who experience a gain should become less likely to proceed to next rounds, while those who experience a loss should become more likely to proceed to next rounds, which is consistent with the definition of the disposition effect. Our task is similar to the test of the hot-hand fallacy or the gambler's fallacy. However, only the gambler's fallacy is consistent with the disposition effect: both can be explained by mean reversion and/or different risk attitudes in the gain and loss domains. It is possible that our task captures the same determinants underlying the disposition effect and

[1] The detailed construction of the ambiguous lottery is provided in Appendix A. We used an ambiguous instead of a risky lottery to bring our task closer to our experimental asset markets with ambiguous fundamental values. The choice for ambiguous fundamental values in the trading environment was taken to better resemble real stock investments in actual markets with unknown return distributions.

Table 1
The outcomes of the ambiguous lottery in four rounds for each of the six basic tasks.

Tasks	Round 1	Round 2	Round 3	Round 4
1	−400	400	400	400
2	400	400	−400	400
3	400	−400	400	400
4	−400	400	−400	400
5 (L)	−400	−400	−400	−400
6 (G)	400	400	400	400

Notes: Task 5 ("Task L") is used to measure subjects' disposition effect levels in the loss domain, and task 6 ("Task G") is used to measure subjects' disposition effect levels in the gain domain. The order of the tasks was randomized.

the gambler's fallacy. As it will become clear soon, mean reversion is unlikely to apply in our setting as we limit our design to one shock, and subjects know that there is no further signal.

We separately measure the inclination of stopping when experiencing gains and continuing when experiencing losses. To do so, we construct six basic tasks, as described above. Two tasks have a particular sequence of lottery outcomes. The outcomes of the ambiguous lottery are four continuous gains in one basic task and four continuous losses in another, should subjects play to the end. In light of the disposition effect, subjects with a high disposition effect level should stop playing early in the four-gains series and proceed further in the four-losses series. By counting the number of lotteries that subjects play in each of the above two tasks, we are able to separately measure the level of the disposition effect in the gain and loss domains for each subject. The outcomes were more "normal" in the remaining four tasks. Table 1 shows the outcomes of the ambiguous lottery across four rounds in the six tasks. The order of the six tasks was randomized on the individual level. Subjects received an initial endowment of 1600 ECU, which is sufficient to cover any potential losses, and one of the six tasks was randomly chosen for actual payment.

Our task shares features with some of the previous measures, such as the hypothetical "housing task" used in Weber and Welfens (2007a) and the "stock market task" in Weber, Welfens, 2007. Our disposition effect measurement task differs from those measures in two important ways. First, by having the two tasks of four-gains series and four-losses series, we are able to measure the disposition effect in the gain and loss domains separately. We believe such a separation is important. Weber and Welfens, 2007a, 2007b; Weber, Welfens find that both individual disposition effect and market underreaction are asymmetric following an increasing versus a decreasing price trend. One potential reason could be that individuals exhibiting high disposition effect levels in a bull market might not be the same ones who exhibit high disposition effect levels in a bear market, and, consequently, this could result in different market dynamics, such as in prices or volumes. Furthermore, it could be that the overall traders disposition effect levels are weaker in the loss domain than in the gain domain. Second, our task is based on individual decisions rather than market tradings as, for example, the "stock market task" in Weber, Welfens, 2007. Like the "housing task," it gives some distance between the measure and the definition of the disposition effect. This implies that it is more difficult for our measure to work as effectively as the market measure of the disposition effect: our measure would not work unless it captures (at least one of the) actual working mechanisms behind the disposition effect. Given that our measure method is based on a prospect value function, evidence of the effective measurement of the disposition effect with our method supports the hypothesis that prospect theory is indeed an important source for the disposition effect.

2.2. Markets, the asset, and signals

Markets: In each session of the experiment, there were 27 subjects who were assigned into three experimental asset markets. Specifically, we composed each market with nine subjects according to their levels of the disposition effect.[2] The experimental asset markets are similar to those in Plott and Sunder (1982). Each subject received 4000 ECU and 15 units of an ambiguous asset at the start of the market. Trades over the asset took place in an open-book continuous double auction for a trading round of four minutes in total. Short selling and leverage were not allowed. Buy orders could enter the book only when subjects had enough money to pay for the asset, while sell orders were possible only when a seller had enough assets to sell. Historical transaction prices were presented on the trading screen (see Fig. A.2 in appendix).

To investigate the role of the disposition effect in market efficiency following private signals to some informed traders, we divided each trading round into two trading phases. Subjects first traded the asset without private information for two minutes. Trading then paused, and we provided three subjects – informed traders whose disposition effect levels were either the highest or the lowest in the market – with a private signal. The non-informed traders were notified that the informed traders had received the private signal (and thus knew that they were not selected as informed traders). Trading

[2] We ranked the disposition effect levels among all 27 subjects from the highest to the lowest. To achieve sufficient heterogeneity of the disposition effect levels among the subjects in each market, we apply the following rule of assignment: the ith market, $i \in \{1, 2, 3\}$ was composed of subjects whose rank equaled $i + 3x$, with x ranging from 0 to 8 in steps of one. We classified subjects that decided not to play any lottery in the disposition effect measurement task as a non-informed trader. This is because in these cases, the subjects could not be classified as either high or low disposition effect individuals.

Table 2
The eight treatments.

Round	1	2	3	4	5	6	7	8
Domain where the disposition effect is measured	Gain (Rounds 1 to 4)				Loss (Rounds 5 to 8)			
Informed traders' disposition effect levels	High	Low	High	Low	High	Low	High	Low
Type of signal	Pos.	Neg.	Neg.	Pos.	Neg.	Pos.	Pos.	Neg.

Notes: The experiment consisted out of 8 rounds. In the first (final) 4 rounds the informed traders' disposition effect was measured in the gain (loss) domain. In the odd (even) rounds the three subjects with the highest (lowest) disposition effect levels were appointed as informed traders. Per round a specific price signal, positive (abbreviated as Pos.) or negative (abbreviated as Neg.), was provided to the informed traders.

continued for two further minutes after the private signal was provided. The existence of informed traders and the structure of signals were common knowledge, but subjects did not know who would be an informed trader when entering the first trading phase of the market. A comparison of the trading dynamics between markets where informed traders have the highest disposition effect levels and markets where informed traders have the lowest disposition effect levels allow us to directly examine the influence of the disposition effect on the market efficiency. See Appendix A for more details about the experimental asset markets.

The ambiguous asset: The per unit, called "share" in the experiment, value of the ambiguous asset was determined by the color of a randomly drawn ball from a bowl containing 100 balls with an unknown color composition. The per share value of the ambiguous asset was 0 ECU for a black ball, 100 ECU for a white ball, 600 ECU for a yellow ball, and 700 ECU for a purple ball. The "naive" fundamental value was thus 350 ECU if subjects consider all colors equally likely, and they are ambiguity and risk neutral. We use the ambiguous asset instead of the risky asset to more closely resemble actual stock markets. Subjects were told that before trades took place, a ball was drawn from the bowl independently for each market, with the color of the drawn ball first hidden and announced after the market closed.

Signals: As explained above, after the first trading phase and during the trading pause, the informed traders received a private signal. The private signal excluded one potential color of the drawn ball. The positive signal excluded the white color (eliminating the possibility of 100 ECU), and as a result, the naive expected value of the asset increased from 350 ECU to 433.33 ECU. Conversely, a negative signal excluded the yellow color (eliminating the possibility of 600 ECU), and the naive expected value dropped from 350 ECU to 266.66 ECU. Note that after the signal, the worst state – the drawn ball is black – and the best state – the drawn ball is purple – remain. Note also that the standard deviation of the assets expected value (309.12) is equal following a positive or negative signal, while the skewness differs only in sign (0.65 and −0.65 following a positive and negative signal, respectively).

Matching signals with the measure of the disposition effect: We determined the informed traders once according to the disposition effect measure in the gain domain and once according to the disposition effect measure in the loss domain. The informed traders can receive a positive signal or a negative signal. In general, market prices rise following a positive signal, and market prices decline following a negative signal. This allowed us to construct markets where the type (positive versus negative) of the signal either matches or does not match the measurement domain (gain versus loss) of the disposition effect according to which informed traders are determined. We say the domain matches the signal when the disposition effect is measured in the gain domain and the signal is positive (thus the market is rising and traders are more likely making gains), and when the disposition effect is measured in the loss domain and the signal is negative (thus the market is declining and traders are more likely making losses). We say the domain does not match the signal otherwise.

We chose this design because we wanted to examine whether the different domains in which the disposition effect is measured affect market efficiency differently in rising markets versus in declining markets. If the disposition effect measured in the gain domain is fundamentally different from that measured in the loss domain, only the disposition effect measured in the gain domain should affect market efficiency in a rising market. Similarly, only the disposition effect measured in the loss domain should affect market efficiency in a declining market.

Treatments: To accommodate all possibilities mentioned above, we had a $2 \times 2 \times 2$ design: 2 types of informed traders (the highest/the lowest disposition effect levels) $\times$ 2 measures of the disposition effect (measured in gain/loss domain) $\times$ 2 types of signals (positive/negative). Table 2 summarizes the eight treatments and the rounds in which each treatment took place.

2.3. Measuring ambiguity attitudes

As subjects faced an ambiguous lottery in the measurement of the disposition effect levels and traded an ambiguous asset in the experimental asset markets, we measured ambiguity attitudes in the final part of our experiment (see Appendix A for instructions). Specifically, subjects were first asked to pick a color, either white or black. Then, subjects faced a choice list with eleven rows. In each row, there was a risky and an ambiguous urn. The unknown composition of white and black balls in the ambiguous urn remained constant across rows. The risky urn in each row contained a known composition of white and black balls, but the proportion changed across rows (see Fig. A.3 in appendix for the list). Subjects were asked to choose between the ambiguous and risky urn at each row. Subjects were told that one of the eleven rows would be randomly selected for payment. A ball would be drawn from the chosen urn by the computer. The subject would receive 800 ECU should the drawn balls color match the color chosen by the subject.

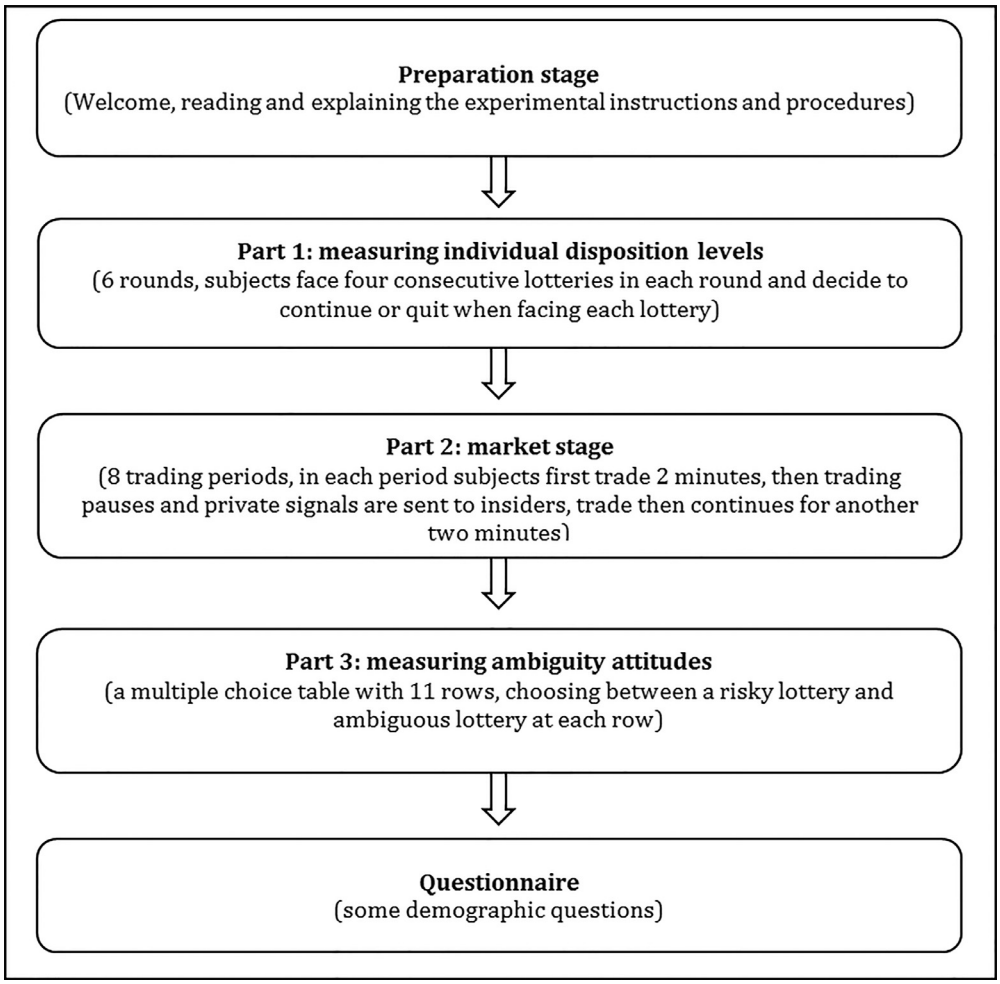


Fig. 1. Experimental procedure.

We use the average of the two winning probabilities of the two risky urns at and below the switching row as the "matching probability." A matching probability lower (higher) than 0.5 is interpreted as ambiguity aversion (or ambiguity seeking, respectively). This method measures ambiguity attitudes independent of risk attitudes (Wakker, 2010) and is frequently used in the literature (e.g., Cavatorta and Schröder, 2019; Dimmock et al., 2015; Lauriola and Levin, 2001).

2.4. General procedures

We ran six experimental sessions with 27 subjects each (162 subjects in total) in the Individual Decision lab at Radboud University, The Netherlands. All experiments were programmed using z-Tree (Fischbacher, 2007), and subjects were recruited using ORSEE (Greiner, 2004). Each session lasted approximately 1 h and 30 mins. Subjects average earning was 17.01 euro. Payments were paid out in cash at the end of each session. The experiment is depicted schematically in Fig. 1.

2.5. Hypotheses

By combining the argumentation and prior literature presented in the introduction with the experimental design presented in this section, we are able to formulate the following three hypotheses.

Hypothesis 1. Informed traders with high disposition effect levels have a higher (lower) willingness to hold the asset following a negative (positive) signal than informed traders with low disposition effect levels.

We measure the willingness to hold the asset with the numbers of (submitted and accepted) bids and asks, bid prices and ask prices, and trading volumes. A higher (lower) willingness to hold the asset corresponds to submitting more (fewer) bids and/or fewer (more) asks, quoting higher (lower) bid prices and/or higher (lower) ask prices, and holding more (fewer) assets in the end.

The private signal is only in the hands of informed traders. For market prices to reflect the private signal, informed traders must initiate trades, and only through their trading can the private signal be transmitted into market prices. In light of the disposition effect, there are two possibilities that are not mutually exclusive. In the first possibility, market prices are affected by the general disposition effect levels in a market. In our experiment, the general disposition effect levels in different treatments are similar. This leaves us with the second possibility, which is also our main focus. In the second possibility, market prices are directly affected by the disposition effect levels of the informed traders. Following a positive (negative) signal, informed traders with high disposition effect levels are likely to submit asks (bids) with lower (higher) prices, resulting in weaker buying (selling) forces. Weaker forces are then expected to slow down the process by which market prices are adjusted to the new equilibrium level. This leads to our second hypothesis about market efficiency:

Hypothesis 2. Following a signal, markets with informed traders with high disposition effect levels exhibit stronger price underreaction than markets with informed traders with low disposition effect.

However, as we explained in Section 2.2, we only expect the above hypotheses to hold when informed traders disposition effect levels are measured in a domain (gain/loss) that matches the sign of the private signal (positive/negative). This leads to the third hypothesis:

Hypothesis 3. Hypothesis 1 and Hypothesis 2 hold only when the informed traders' disposition effect levels are measured in the domain that matches the sign of the private signal.

Hypothesis 3 is consistent with field data and a finding in Weber and Welfens (2007a). They find that individual behavior in the two domains is unrelated; there is no systematic correlation between the proportions of winners and losers realized following a positive and negative signal. Results in support of Hypothesis 3 would suggest the importance of eliciting the disposition effect in the loss and gain domains separately.

3. Experimental results

In the report of our experimental results, we proceed as follows. Section 3.1 discusses the individual disposition effect levels that were separately measured in the gain and loss domains as well as their relationship with ambiguity attitudes. We examine Hypothesis 1 and 2 in Section 3.2 by comparing trading behavior, market prices, and price underreaction in markets with high and low disposition informed traders. Section 3.2 considers only markets in which the disposition effect levels according to which the informed traders were selected were measured in a domain (gain/loss) that matches the sign of the private signal (positive/negative).

Hypothesis 3 is examined in Section 3.3, in which we investigate the markets in which the informed traders disposition effect levels were measured in a domain that is different from the sign of the private signal. Comparing trading behavior in Section 3.3 with those in Section 3.2 allows us to check whether the disposition effect measured in the gain and loss domains has different behavioral implications.

All numbers reported below relating to trading quantities reflect the average per-person behavior of the nine-person asset markets. Unless explicitly stated otherwise, a significant difference is over the whole post-signal period.

3.1. Individual disposition effect levels

As mentioned in Section 2.1, we used the four-gains series to measure subjects disposition effect in the gain domain, and the four-losses series to measure subjects disposition effect in the loss domain. Concretely, for each subject, we count the number of lotteries that he/she played in the four-gains series and the four-losses series. This means that for both the disposition effect measured in the loss and gain domain, each subject receives a level ranging from 0 to 4, with subjects deciding not to play any lottery having a level of 0, while subjects deciding to play all four lotteries have a level of 4. Based on the prospect value function, we posit that the later (or earlier) a subject quits at the four-losses series (the four-gains series, respectively), the higher his/her disposition effect level in the loss (gain) domain is. For sake of comparability between the measures in the gain and loss domains, we invert the scale for the four-gains series. Hence, a level of 4 indicates the highest level of the disposition effect in both the loss and gain domains. This construction is consistent with the basic idea of the disposition effect: holding a loser for as long as possible or selling a winner as soon as possible.

Table D.11 shows the frequency distribution of the individual disposition effect levels measured in the lottery task. As can be seen, the distribution of the disposition effect levels in the loss domain first degree stochastically dominates that in the gain domain, suggesting a stronger disposition effect in the loss than in the gain domain. Moreover, we find a negative but statistically insignificant correlation of -0.105 between individuals disposition effect levels in the gain and loss domains (Spearman correlation test, $p = 0.182$). The lack of a positive correlation as well as the fact that the disposition effect seems more pronounced in the loss domain suggest that the two measures capture fundamentally different information. Hence, using one general measure for both domains might neglect these differences in information. For example, given our results above, it could be that the disposition effect is stronger in bear markets than in bull markets, and that different investors are driving the disposition effect in the two kinds of markets. In subsections below, we examine more concretely the behavioral implications of the disposition effect in the two different domains.

Table 3
Informed trader disposition effect levels.

	High disposition informed traders	Low disposition informed traders	Mann Whitney U test
Gain domain	2.94	0.14	0.000
Loss domain	4.00	2.24	0.000

Notes: Disposition effect levels for informed traders are measured in both the gain and loss domains. The final column provides the p-values of a Mann Whitney U test for differences in disposition effect levels between high and low disposition informed traders both in the gain and loss domains.

In our experiment, we examine how private information given to informed traders of high disposition effect levels or low disposition effect levels is translated into market prices. Informed traders of high (or low) disposition levels were the three traders with the highest (lowest, respectively) disposition effect levels in a market. For this design to be effective, we need to ensure that there is a sufficiently large difference in the disposition effect levels of informed traders of high and low disposition effect levels. This is indeed the case in our experiment. As we can see from Table 3, the mean disposition effect levels of the high and low disposition informed traders in the gain and loss domains are economically and statistically significantly different (2.94 versus 0.14 in the gain domain and 4.00 versus 2.24 in the loss domain; Mann Whitney U tests $p = 0.000$ in both domains).[3]

The lottery used in the measurement of the disposition effect is ambiguous. One might suspect a connection between subjects ambiguity attitudes and the disposition effect levels. We find no significant correlation between individual ambiguity attitudes (as measured by the task discussed in Section 2.3) and disposition effect levels in the gain domain (Spearman correlation coefficient=-0.048; $p = 0.548$) nor in the loss domain (Spearman correlation coefficient=0.017; $p = 0.835$).[4]

3.2. Markets of high versus low disposition informed traders

In this part, we consider markets where the sign of the signal matches the domain in which the disposition effect levels of the informed traders are measured. Thus, we consider markets where the informed traders were determined based on the disposition effect measured in the gain domain and received a positive signal, and markets where the informed traders were determined based on the disposition effect measured in the loss domain and received a negative signal. We compare performance in markets with informed traders of high versus low disposition effect levels. In the analysis, we start with individual trading behavior, such as the numbers of (submitted or accepted) bids and asks, the (submitted or accepted) bid and ask prices, and the actual prices at which subjects bought or sold. We then move on to aggregate data, such as market prices and price underreactions. Please note that all p-values below are obtained using a Wilcoxon signed rank test unless otherwise stated.

3.2.1. The willingness to hold the asset after a signal

The disposition effect dictates a weaker (stronger) willingness to hold the asset following a price increase (decrease, respectively). After a positive signal, the average transaction price increases significantly (an average increase of 5.73%, $p = 0.000$), while after a negative signal, the average transaction price decreases significantly (an average decrease of 10.39%, $p = 0.011$).[5] Hence, as suggested by Hypothesis 1, following a positive (negative) signal, we should expect high disposition informed traders to have a weaker (stronger, respectively) willingness to hold the asset than low disposition informed traders. Our first result presents the informed traders' willingness to hold the asset.

Observation 1. Consistent with Hypothesis 1, following a positive (negative) signal, the informed traders of high disposition effect levels are less (more, respectively) willing to hold the asset than the informed traders of low disposition effect levels.

Support for Observation 1: There is no universally accepted measure to capture the willingness to hold the asset. We try to capture it via multiple dimensions. We first consider directly the numbers of bids or asks. Intuitively, if an informed trader is less willing to hold the asset, he/she should submit more asks and/or fewer bids, accept more bids and/or fewer asks, and buy less and/or sell more. Similarly, if an informed trader is more willing to hold the asset, he/she should submit more bids and/or fewer asks, accept more asks and/or fewer bids, and buy more and/or sell less. Table 4 summarizes this information.[6,7] A positive (negative) percentage implies more (less) active behavior – buying or selling – by the high dispo-

[3] In our setting, the traditional Odean (1998) measure is not appropriate because the traders in our experiment received shares as an endowment rather than purchasing in the market as in Odean (1998). Specifically, for subjects who trade infrequently the measure is not reliable because of limited data points. The measure can be provided upon request.

[4] We excluded subjects with multiple switching points or those who picked either the risky or ambiguous urn in all instances (3% of cases) from this analysis.

[5] The price reactions to signals suggest that traders do not apply the Maxmin rule to evaluate the ambiguous assets (Gilboa and Schmeidler, 1989).

[6] The Wilcoxon test in Table 4 is performed by calculating the amount of bids, asks etc for every second following the price signal for both the low and high disposition informed traders. These values are then matched and a Wilcoxon test is used to test for the significance of these differences. This means that a total of 120 (number of seconds following the signal) times 2 = 240 values are used for the Wilcoxon test.

[7] The data on the number of (submitted and accepted) bids and asks placed per second per market in different rounds both before and after the price signal, with the post-signal data separated in insider and outsider order placement, could be found in Tables D.1 and D.2 in appendix. The percentage

Table 4
Percentage differences in the trading behavior between informed traders of high and low disposition levels.

Type of signal	The percentage differences between informed traders of high and low disposition effect levels in the volume of					
	Bids	Asks	Accepted bids	Accepted asks	Bought	Sold
A positive signal	−63.43***	54.33***	61.11	−21.77	−34.08***	106.00***
A negative signal	−3.40	−1.17	−27.84*	94.29**	36.49**	−28.39**

Notes: Wilcoxon tests for significance are for the entire trading phase after the signal: *** stands for $p < 0.01$, ** stands for $p < 0.05$, * stands for $p < 0.1$.

sition informed traders. Second, we construct two comprehensive proxies. In the first comprehensive proxy, we compare the change in the number of submitted asks and bids of the informed traders after receiving a signal. The measure is obtained by subtracting the ratio of mean number of asks per second after and before receiving a signal from the ratio of mean number of bids per second after and before receiving a signal.[8] This proxy, which we dub I_{B-A}^{submit} (with A standing for asks and B standing for bids), increases when informed traders are more willing to hold the asset following a private signal. In a similar fashion, in the second comprehensive proxy, we compare the change in the number of accepted asks and bids of the informed traders after receiving a signal. We denote the second proxy by I_{B-A}^{accept}.[9]

As we can see from the top half of Table 4, following a positive signal, the informed traders of high disposition effect levels on average have significantly lower numbers of submitted bids and higher numbers of submitted asks; they bought less and sold more than the informed traders of low disposition effect levels ($p < 0.01$ for all measures). High disposition informed traders also accept more bids and fewer asks than the low disposition informed traders, although both differences are statistically insignificant ($p > 0.10$). According to I_{B-A}^{submit}, following a positive signal, the willingness to hold the asset equals 11.40 for the markets of the high disposition informed traders, which is significantly lower than the value of 129.47 for the markets with the low disposition informed traders. The proxy I_{B-A}^{accept} gives the same result: I_{B-A}^{accept} equals 60.33 for the high disposition informed traders and 112.38 for the low disposition informed traders. Thus, following a positive signal, both proxies indicate a stronger willingness of the high disposition informed traders to sell the asset than that of the low disposition informed traders.

Following a negative signal, as we can see from the bottom half of Table 4, the informed traders of high disposition effect levels accept fewer bids but more asks, and generally buy more and sell less than the informed traders of low disposition effect levels. The differences, with the exception of the number of submitted bids and asks, are statistically significant.[10] The proxies I_{B-A}^{submit} and I_{B-A}^{accept} confirm that the high disposition informed traders are more inclined to hold the asset. The value of I_{B-A}^{submit} equals -85.92 for the informed traders of high disposition effect levels and -102.34 for the informed traders of low disposition effect levels. The value of I_{B-A}^{accept} equals -28.19 for the informed traders of high disposition effect levels and -80.72 for the informed traders of low disposition effect levels. Both proxies thus show a stronger willingness to hold the asset for the high disposition informed traders than for the low disposition informed traders following a negative signal.

A further finding consistent with the disposition effect is the asymmetry of significance between submitted and accepted bids and asks. The disposition effect predicts active selling following a positive signal and passive holding following a negative signal. Active selling implies initiating more trades, and passive holding implies that traders prefer to accept rather than initiate trades. This is exactly what we observed. The difference in the willingness to sell the asset is significant only in the active trading of submitted bids and asks, while the difference in the willingness to buy the asset is significant only in the passive trading of accepted bids and asks.

3.2.2. Share holdings

Given that the high disposition informed traders have a weaker (stronger) willingness to hold the asset following a positive (negative) signal than their low disposition counterparts, we would expect the high disposition informed traders to hold fewer (more) shares following a positive (negative) signal. Our next observation discusses this.

Observation 2. Following a positive (negative) signal, the informed traders of high disposition effect levels hold significantly fewer(more, respectively) shares than informed traders of low disposition effect levels.

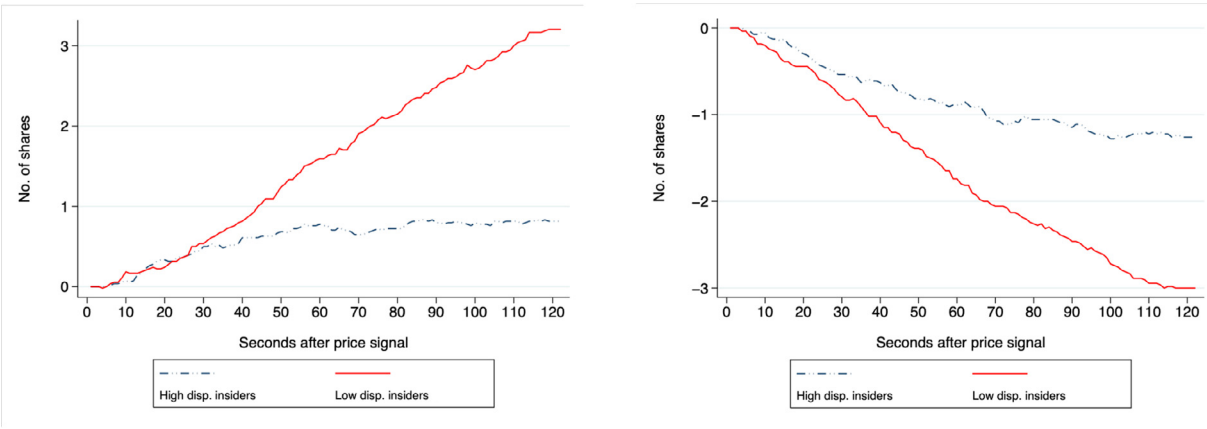
Support for Observation 2: Fig. 2 depicts the post-signal share holdings for informed traders of high and low disposition effect levels. The figure on the left is after a positive signal, and the figure on the right is after a negative signal. As we can

differences in the trading behavior between informed traders of high and low disposition effect levels in each 30-second post-signal trading period could be found in Table D.7 in appendix.

[8] Specifically, let $m(A)$ ($m(B)$) denote the mean number of the informed trader asks (bids) per second after receiving the signal, $m(a)$ ($m(b)$) denote the mean number of asks (bids) per second made by the same informed traders before receiving the signal, this measure be written as: $m(B)/m(b)$ - $m(A)/m(a)$. Using all pre-signal traders as the benchmark (instead of using only those traders who became informed traders in the second trading phase) leads to qualitatively similar results.

[9] The summary of the two proxies for the eight rounds could be found in Table D.5 in appendix.

[10] We do observe rather big differences within the post signal period when we focus on the different 30-second trading blocks found in Table 4. Especially the percentage differences between the number of submitted bids and asks show a rather erratic pattern throughout the four post-shock trading blocks. The pattern is more stable for the differences in accepted bids and asks, although the 200% difference in terms of accepted asks between the high and low disposition informed traders is a bit of an outlier. Incidentally, it exactly mirrors the 200% difference between the number of accepted bids of high and low informed traders found in markets following a positive signal.



(a) After a positive signal **(b)** After a negative signal

Fig. 2. Average post-signal share build-ups.

Table 5
Percentage differences in prices between markets of high and low disposition informed traders.

Type of signal	The percentage differences between informed traders of high and low disposition effect levels in					
	Bid price	Ask price	Accepted bid price	Accepted ask price	Buy price	Sell price
A positive signal	−6.12	−11.86***	−21.13**	3.29	3.57**	−18.88**
A negative signal	10.04	10.91***	20.35***	1.14	10.12**	11.06***

*Notes:*This table shows the percentage differences in prices between markets of high and low disposition informed traders. Wilcoxon rank-sum test for significance (final row only): *** stands for $p < 0.01$, ** stands for $p < 0.05$, * stands for $p < 0.1$.

see from the left figure, following a positive signal, the informed traders of high disposition effect levels show a consistently slower increase in share holdings than that of low disposition informed traders, suggesting high disposition informed traders stronger post-signal willingness to sell the asset. The right figure is almost the exact inverse of the left figure: following a negative signal, informed traders of high disposition effect levels show a consistently slower decrease in share holding than that of low disposition informed traders, suggesting a stronger willingness to hold the asset of the high disposition informed traders than that of the low disposition informed traders.

3.2.3. Trading prices

So far, we have discussed the impact of the disposition effect on trading behavior. We now move on to trading prices. In light of the disposition effect, following a positive signal, informed traders of high disposition effect levels are more ready to sell the asset. In order to decrease their share holdings faster (or increase slower) than those of the low disposition informed traders, the informed traders of high disposition effect levels should be more likely to sell at a lower price and less likely to buy at a higher price. Similarly, following a negative signal, the informed traders of high disposition effect levels are more willing to hold the asset than the informed traders of low disposition effect. To retain more of their share holdings (or decrease more slowly), the informed traders of high disposition effect levels should be more likely to buy at a higher price or less likely to sell at a lower price. The observation below suggests that this was exactly what our subjects did.

Observation 3. Following a positive (negative) signal, the informed traders of high disposition effect levels ask significantly lower (higher, respectively) prices, accept bids with lower (higher, respectively) prices, and eventually sell the asset at significantly lower (higher, respectively) prices than the informed traders of low disposition effect levels.

Support for Observation 3: Table 5 shows the percentage differences between the high and low disposition informed traders in their submitted bid prices and ask prices, their accepted bid prices and ask prices, and the prices at which they actually bought and sold.[11]

As we can see from Table 5, following a positive signal, high disposition informed traders asked significantly lower prices (-11.86%, $p < .01$), accepted bids with significantly lower prices (−21.13%, $p < 0.05$), and they eventually sold the asset at significantly lower prices (−18.88%, $p < 0.05$). In contrast, following a negative signal, the informed traders of high disposition effect levels asked significantly higher prices (10.91%, $p < 0.05$), accepted bids with significantly higher prices (20.35%, $p < 0.05$), and they eventually sold the asset at significantly higher prices (11.06%, $p < 0.05$).

[11] The data on the submitted and accepted bid and ask prices placed per second per market in different rounds both before and after the price signal, with the post-signal data separated in insider and outsider order placement, could be found in Tables D.3, D.4 and D.6 in appendix. The percentage differences in the trading prices between informed traders of high and low disposition effect levels in each 30-second post-signal trading period could be found in Table D.8 in appendix.

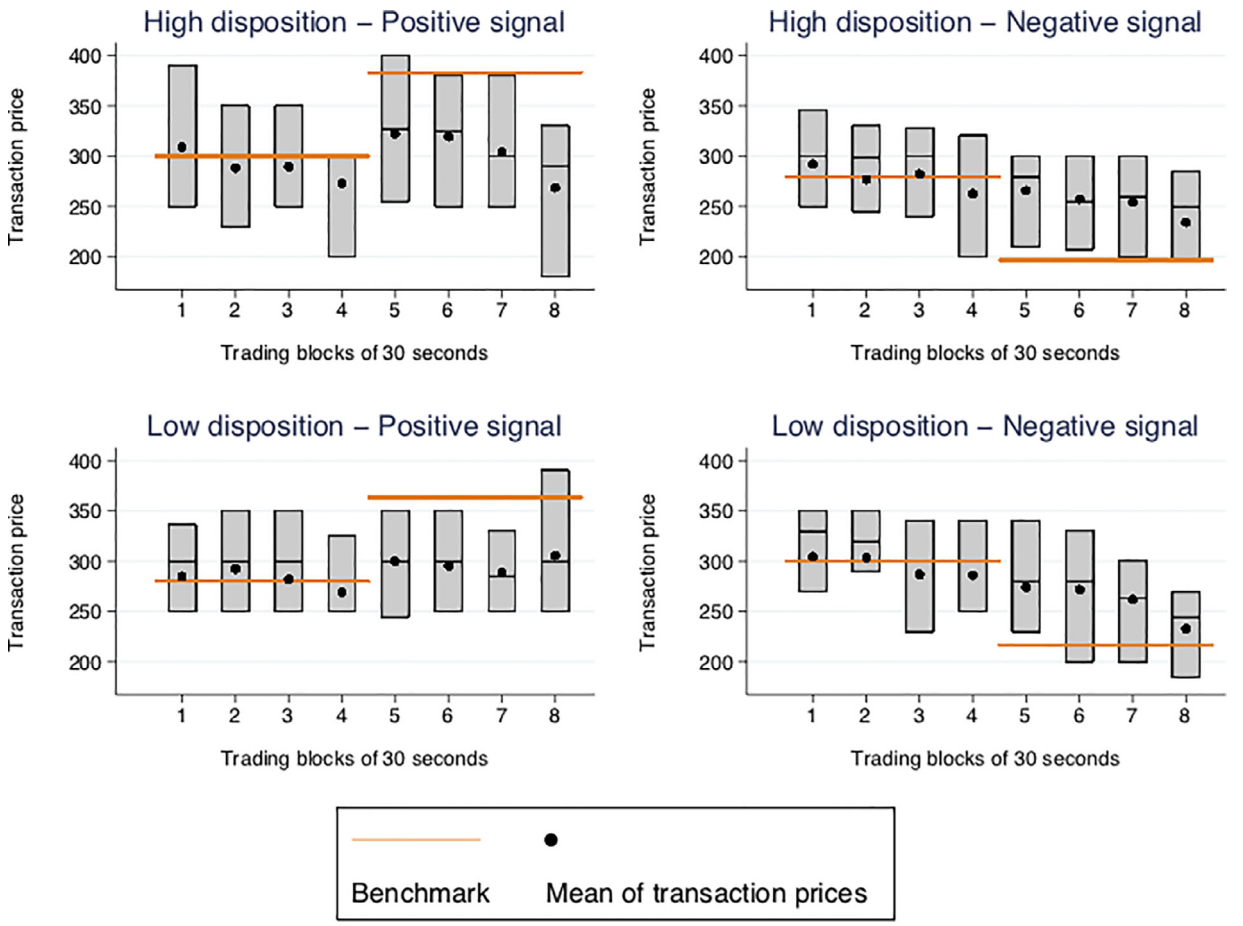


Fig. 3. Box plots and means of transaction prices.

The disposition effect primarily predicts holding or selling behavior rather than buying behavior. Following a positive signal, it predicts a stronger tendency to sell, while following a negative signal, it predicts a stronger tendency to hold. Indeed, as we can see from Table 5, consistent with the disposition effect, differences in the buying behavior is less clear. In Table 5, the measures pointing to buying behavior include the differences in submitted bid prices, their accepted ask prices, and the prices that were actually bought. Following either signal, the differences are insignificant in terms of bid prices and accepted ask prices. There is a significant difference with the bought prices ($p < 0.05$), but following a positive signal, the sign is on the wrong direction, and the economic magnitude (3.57%) is comparatively smaller than the differences in ask prices, accepted bid prices, and selling prices.

3.2.4. Market prices

Finally, we move on to market prices. The following observation summarizes the main finding.

Observation 4. On a market level, (a) there is a significant underreaction of market prices in all markets; (b) there is a tendency that price underreaction in markets with high disposition informed traders is stronger than that of markets with low disposition informed traders; (c) the tendency exists following both positive and negative signals, but the underreaction is stronger and more consistent following a negative signal.

Support for observation 4a: Fig. 3 presents the price paths and the respective price benchmarks corrected for the uncertainty premium[12] in the respective markets. We observe a significant underreaction in all markets. Furthermore, in general, there is no clear momentum of market prices toward the new fundamental level. So, it seems markets indeed need more time to reflect private information than public information. Comparing markets of high and low disposition informed traders,

[12] Please note that as the uncertainty premium can (and does) differ between different trading rounds in our experiment, we cannot simply compare the raw price levels between rounds. Instead, we correct for this by adding the uncertainty premium calculated for a particular round to the post-signal (bid-, ask-, accepted bid-, accepted ask-, buy- and sell-) prices of that particular round. However, not correcting for differences in the uncertainty premium does not qualitatively change our results. Here the uncertainty premium equals 50 for markets of high disposition informed traders and 70 for markets of low disposition informed traders.

Table 6
Underreaction in markets of informed traders.

Type of signal	Markets	Post-signal trading block (30 s. each)				
		1	2	3	4	ALL
A positive signal	Markets of high disposition informed traders	15.90***	16.65***	20.76***	29.93***	20.27***
	Markets of low disposition informed traders	16.53***	17.71***	19.50***	14.99***	17.79***
	Difference between the two markets	−0.63	−1.06	1.26	14.94**	2.48
A negative signal	Markets of high disposition informed traders	35.17***	30.62***	29.34***	19.06***	29.09***
	Markets of low disposition informed traders	26.54***	25.42***	20.80***	7.27*	21.09***
	Difference between the two markets	8.63*	5.20	8.54**	11.79*	8.00***

*Notes:*This table shows the underreaction (in percentages) in markets of high and low disposition informed traders and the differences between the two. Mann Whitney U test (first two rows) and Wilcoxon test (final row) for significance: *** stands for $p < 0.01$, ** stands for $p < 0.05$, * stands for $p < 0.1$.

we observe a significant increase in the average transaction price (4.75%, $p = 0.018$) following the positive private signal in markets with high disposition informed traders. In markets with low disposition informed traders, the average transaction price increases as well, but the difference (4.47%) is insignificant ($p = 0.392$). Following a negative signal we observe a significant decrease in the average transaction price in both markets with high disposition informed traders (−9.43%, $p = 0.000$) as well as in markets with low disposition informed traders (−11.19%, $p = 0.000$).

Support for observation 4b: Hypothesis 1 and the results in Tables 4 and 5 suggest that, the high disposition informed traders have a stronger willingness to sell the asset following a positive signal, and are less willing to sell the asset following a negative signal. These trading behaviors might distort the market prices. To measure this distortion, we compute, following each type of signal, the percentage differences between the average transaction price, T_i, in the ith post-signal 30-second trading block and the respective benchmark B.[13]

Table 6 presents the percentage amount of underreaction as compared to the market-specific benchmark in both markets and the differences in underreaction between the two markets. Overall markets with the high disposition informed traders underreact more strongly than markets with the low disposition informed traders (20.27% versus 17.79% following a positive signal and 29.09% versus 21.09% following a negative signal).

Support for Observation 4c: The underreaction is weak following a positive signal: the difference between the two markets is insignificant overall ($p > 0.10$) and is significant only in the fourth trading block (29.93 versus 14.99, $p < 0.05$). The underreaction is stronger and more consistent following a negative signal: the difference between the two markets is significant overall ($p < 0.01$) and is significant in three of the trading blocks. The last result is consistent with the finding in Section 3.1 that the disposition effect is stronger in the loss domain than in the gain domain. This result is related to loss aversion in prospect theory: Investors are particularly averse to selling losing stocks because realizing losses is painful (Barberis and Xiong, 2009; 2012; Shefrin and Statman, 1985).

The comparison of Observations 1 to 3 with Observation 4 reveals one discrepancy between individual trading behavior and the aggregate market outcome. Despite strongly consistent trading behavior with the disposition effect at the individual (informed traders) level, in the aggregate we observe only a weak tendency in market price underreaction. Price underreaction in the market with the low disposition informed traders is comparable with the market consisting of the high disposition informed traders. This is because after a positive signal, the low disposition effect informed traders ask for a high price, but the non-informed traders consisting of low to medium disposition effect are not willing to buy at this high price, and therefore few transactions take place. Also, the low disposition informed traders do not have to bid at higher prices because the non-informed, low to medium disposition effect traders are readily willing to accept these low bids. As a consequence, the market prices after a positive signal did not increase. For more detail please see the analysis in Appendix B. Furthermore, although we have markets of high and low disposition informed insiders, the overall disposition effect levels are the same across those markets. Thus, the differences in market prices are purely driven by the differences in the disposition effect levels of informed traders. This is unlike Weber and Camerer (1998) and Weber and Welfens, 2007a, 2007b; Weber, Welfens where markets consist of either all high disposition traders or all low disposition traders, and difference in market price reaction is obtained by comparing the markets of high disposition traders with those of low disposition traders. This potential explanation in line with the finding of other studies that markets with heterogeneous traders are robust to various kinds of biases.[14]

3.3. When the sign of the signal mismatches the disposition effect measure

We have thus far discussed markets where the sign of the signal matches the domain in which the informed traders disposition effect levels are measured. We now move on to markets where the sign of the signal does not match the domain in which the informed traders disposition effect levels are measured. Thus, we are considering markets where the informed

[13] Specifically, following a positive signal, underreaction in the trading block i is defined as $(B_{pos} - T_i)/B_{pos}$, where B_{pos} is the benchmark following a positive signal. Following a negative signal, underreaction in the trading block i is defined as $(T_i - B_{neg})/B_{neg}$, where B_{neg} is the benchmark following a negative signal.

[14] For example, Füllbrunn et al. (2014) find that while individual traders are ambiguity averse, because of the heterogeneity of individual attitudes toward ambiguity, there is no ambiguity aversion on the aggregate market level.

traders are selected based on the disposition effect levels measured in the loss (gain) domain, but they receive a positive (negative, respectively) signal. Those markets should deliver qualitatively the same results if the disposition effect measured in the gain domain and in the loss domain capture qualitatively the same information. Significant differences in the results of markets examined in this subsection and those of markets considered in Section 3.2 would, however, suggest that general measures ignoring the domain where the disposition effect is measured are unlikely to predict accurately the behavior of traders in bear and bull markets at the same time.[15]

Indeed, in general we find that when the sign of the signal does not match the domain in which the informed traders disposition effect levels are measured, results are qualitatively different from Observations 1 to 4. The results are summarized in the following observation. Detailed evidence of the observation can be found in Appendix C.

Observation 5. When the sign of the signal does not match the domain in which the informed traders disposition effect levels are measured, there are no consistent differences between the informed traders of high and low disposition effect levels in (a) the willingness to hold the asset, (b) the share holding, (c) the trading prices, and (d) underreaction of market prices.

Specifically, unlike results in Section 3.2, the high disposition informed traders accept significantly fewer (more) bids and sell significantly less (more) than the low disposition informed traders following a positive (negative) signal. The significant difference in share holdings found in Fig. 2 between the high and low disposition informed traders vanishes in the mismatched markets (see in Fig. C.1). Furthermore, in contrast to Observation 3, there are no consistent differences of trading prices between markets of high and low disposition informed traders, with some measures pointing to the wrong direction. Finally, the underreaction following a positive signal is stronger in markets with the low disposition informed traders than those with the high disposition informed traders, and not significant following a negative signal.

The above results suggest that the disposition effect measure predicts behavior well only when the market price development matches the domain in which the disposition effect is measured. We conclude that the disposition effect measured in the gain domain and in the loss domain are not two sides of the same coin, and a separate elicitation of the disposition effect in the gain and loss domain is necessary. General measures, such as the one in Weber and Welfens (2007a), might not predict behavior well in bear and bull markets at the same time.

4. Conclusion

We have experimentally examined the role of the disposition effect in market underreaction following the arrival of private information to a small group of informed traders. We measured individual disposition effect levels in both the gain and loss domain via a novel method. Subjects then traded an ambiguous asset via a computer-based double auction. During the trading, a (positive/negative) signal was given to some selected informed traders. The informed traders were either of high or low disposition effect levels, which were measured either in the gain domain or in the loss domain. This translates into a $2 \times 2 \times 2$ design: two levels (high/low) of the informed traders disposition effect levels $\times$ two domains (gain/loss) in which the disposition effect levels are measured $\times$ two types (positive/negative) of private signals.

We find, first, that the disposition effect measured in the gain domain is unrelated to that measured in the loss domain. Second, compared to the informed traders of low disposition effect levels, following a positive (negative) signal, the informed traders of high disposition effect levels: (a) are less (more, respectively) willing to hold the asset, (b) hold significantly fewer (more, respectively) stocks, and (c) ask significantly lower (higher, respectively) prices, accept bids with lower (higher, respectively) prices, and eventually sell the asset at significantly lower (higher, respectively) prices. Third, although we find individual behavior to be in line with informed traders disposition effect levels, this only weakly translates to differences in terms of price underreaction between markets of high and low disposition informed traders. Specifically, there is a tendency that price underreaction in markets with high disposition informed traders is stronger than that of markets with low disposition informed traders. The tendency exists following both signals, but the underreaction is more consistent following a negative signal. Finally, we find that results crucially depend on whether the sign of the signal matches the domain in which the disposition effect levels of the informed traders are measured. When the two do not match, a) there are no consistent differences between the informed traders of high and low disposition effect levels in the willingness to hold the asset, the share holding, and the trading prices, and b) there are no consistent differences between the informed traders of high and low disposition effect levels in underreaction.

Our results have important policy implications. Consistent with previous research on the disposition effect, our paper provides further support to the influence of the disposition effect on market efficiency. This result suggests that introducing measures to protect investors from the disposition effect, such as more active usage of the automatic “stop loss” orders (Fischbacher et al., 2017), not only benefits individual investors but also the market as a whole. Banks providing investment advice to their customers could also benefit from our findings. There are two sides of the disposition effect and the impacts of the disposition effect on market prices are asymmetrical. These findings suggest that different populations of investors

[15] In reality when financial markets are in a bear market, a single positive shock does mean traders are making profits. Quite the opposite, most of them may experience losses and perceive themselves in the loss domain. This is different in our experiment. In our experimental design markets were initially in a neutral position. There were no positive nor negative signals. We then controlled the market trend through releasing a positive or negative signal. Intuitive and confirmed in experimental results, markets rise following a positive signal and decline following a negative signal. Therefore, the market trend and the sign of signal types were always in the same direction.

suffer from the disposition effect in bear markets and in bull markets. It is therefore important for banks to tailor the investment advice not only to different types of investors but also to different market conditions.

To conclude, we thus observe both the individual behavior and the aggregate market behavior to be generally in line with Hypotheses 1 and 2. The relatively weak evidence for Hypothesis 2, however, suggests that the strong impact of the disposition effect bias on individual behavior does not work through as strongly into aggregate market prices. Note that price formation is the result of many dynamic interactions, including, for example, the trading strategies of informed traders and outsiders, the capital constraints, the asset positions, and the learning of outsiders. The disposition effect is, of course, just one of the forces at play. Thus, the finding that there is stronger support for Hypothesis 1 than for Hypothesis 2 might not be too surprising after all. Finally, the clearly supportive evidence in line with Hypothesis 3 stresses the importance of distinguishing the disposition effect in the gain and loss domain. This might be of particular interest for future research.

Appendix A. Experimental instructions

Welcome

Thank you for participating in this experiment. By showing up on time you receive a s show-up fee of 4 Euro. The purpose of this experiment is to understand how people behave in certain situations. There are no right or wrong answers. Please make the choice that you feel most comfortable with. Your identity will never be revealed; others will not be able to identify you with the choices you made.

In the experiment you will be able to make some money. The amount of money you can make depends on your choices and some luck. The money you earn will be immediately paid out to you in private after the experiment.

If you have any question during the experiment, please raise your hand. An experimenter will come to you and answer your questions individually. Please put your cell phone on airplane mode and do not talk with other participants in the experiment; otherwise, we may be forced to exclude you from the experimental payment.

The experiment consists of three parts. Detailed instruction for each part is provided below and also shown on the computer screen before that part starts. In the experiment we talk about Experimental Currency Units (ECU) instead of Euro.

The exchange rate between ECU and euro is **1000 ECU = 1 Euro**

Measuring individual disposition levels

You face six rounds in this part of the experiment. In each round you face a lottery. There is a computerized bag with 10 balls, which are either black or white but are of unknown proportion. The bag remains unchanged in each round. The lottery is such that you gain 400 ECU (+400 ECU) if the drawn ball is white and lose 400 ECU (- 400 ECU) if the drawn ball is black. Here the ball is drawn with replacement. You need to decide whether you want to play the lottery.

If you decide not to play the lottery, the round ends and the next round begins. If you decide to play the lottery, the payment of the lottery will be immediately determined by the computer and given to you. In each round you can play the lottery sequentially up to four times.

At the end of the experiment, one of the six rounds will be randomly chosen by the computer to determine your payment in part 1. Your earning in part thus equals the payments from the lottery of the randomly chosen round.

Market stage

Instructions for subjects: In this part of the experiment, you are one of the nine traders in a stock market. There are 8 trading rounds. Each trading round lasts 5 minutes. You trade a stock, and trading relates to units of the stock ("share" hereafter). One share is one unit of the stock.

The value of each share is determined as follows. There is a box with 100 balls of four colors: black, white, yellow and purple, but you don' t know the proportions of these colored balls. The proportions of the colored balls are changed in each round. At the beginning of each trading round, a ball will be drawn randomly from the box, and the color of the ball determines the value of each share. The color of the ball will be revealed at the end of the trading round. Black ball corresponds to 0 ECU for each share, white ball corresponds to 100 ECU for each share, yellow ball corresponds to 600 ECU for each share, and purple ball corresponds to 700 ECU for each share. That is:

The Box				
The color of the drawn Ball	Black	White	Yellow	Purple
Value of each share	0 ECU	100 ECU	600 ECU	700 ECU

At the beginning of each round, you receive an initial endowment. You then have 2 minutes to trade with other participants in the stock market. For detailed instruction on trading screen and trading rules please see the trading instruction sheet that have been provided to you. After 2 minutes trading pauses, and three of the nine traders receive a private signal.

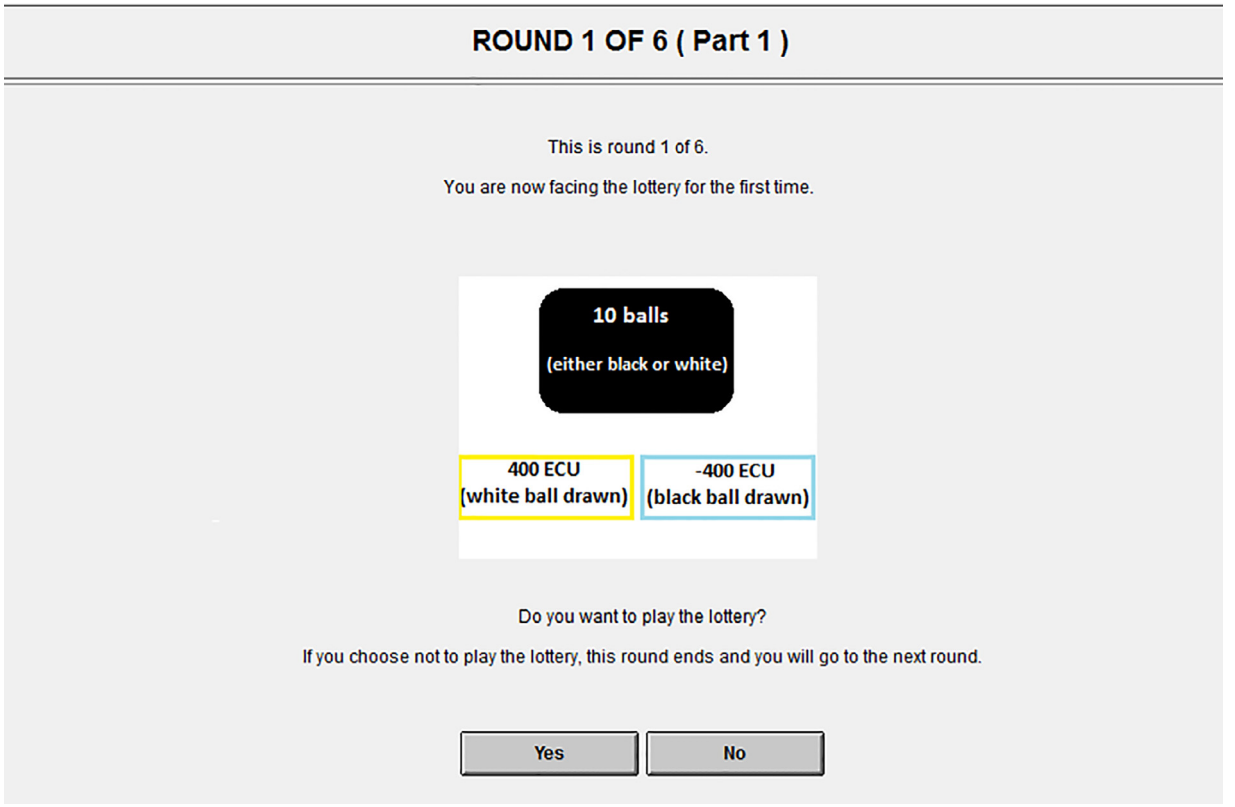


Fig. A.1. Lottery task.

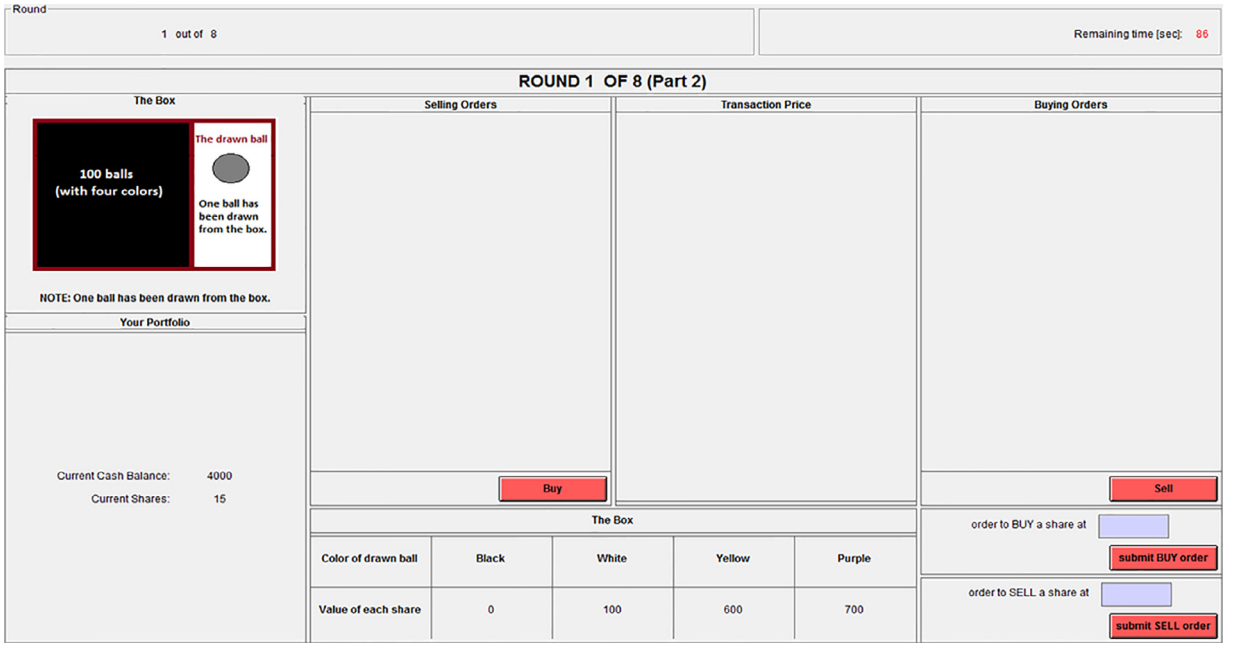


Fig. A.2. Trading screen.

Part 3 of the experiment

Please note that the color of the ball you have chosen to yield payment is: WHITE.

Now please choose for each situation from which urn you prefer to draw a ball; urn 1 or urn 2?

Choice Task Table

You earn 800 ECU if the color of the drawn ball is WHITE.

	URN 1	URN2	Your Choices
0	0 white balls, 10 black balls	unknown composition	Urn 1 ○ ○ Urn 2
1	1 white balls, 9 black balls	unknown composition	Urn 1 ○ ○ Urn 2
2	2 white balls, 8 black balls	unknown composition	Urn 1 ○ ○ Urn 2
3	3 white balls, 7 black balls	unknown composition	Urn 1 ○ ○ Urn 2
4	4 white balls, 6 black balls	unknown composition	Urn 1 ○ ○ Urn 2
5	5 white balls, 5 black balls	unknown composition	Urn 1 ○ ○ Urn 2
6	6 white balls, 4 black balls	unknown composition	Urn 1 ○ ○ Urn 2
7	7 white balls, 3 black balls	unknown composition	Urn 1 ○ ○ Urn 2
8	8 white balls, 2 black balls	unknown composition	Urn 1 ○ ○ Urn 2
9	9 white balls, 1 black balls	unknown composition	Urn 1 ○ ○ Urn 2
10	10 white balls, 0 black balls	unknown composition	Urn 1 ○ ○ Urn 2

OK

Fig. A.3. Ambiguity attitudes measurement task.

The private signal excludes one potential color of the drawn ball. For example, the signal could state that the drawn ball is NOT white. Then trading continues for another two minutes.

Prior to the first trading round there will be *ONE TRIAL ROUND* in which you can familiarize yourself with the trading screen and trading rules. Your decisions in the trial round will *NOT* affect your payoff. At the end of part 2 one trading round will be randomly chosen. Your payment in the chosen round will be your payoff in part 2. Your payment in a trading round = the number of shares in your portfolio at end of the round.

In part 2 of the experiment, buying and selling shares in the stock market will be processed by the computer. During each trading round, you will see the following trading screen.

How to buy a share: If you want to buy a share, you can do so in two ways:

1. When there are sell orders in the "Selling Orders" column that you want to buy, you can directly click on the listed order price at which you want to buy and press the "Buy" button, and the share will be immediately bought.

2. You can enter a price that you are willing to pay in the field above the red button of "submit BUY order", and click the red button ("submit BUY order"). Your buy order will then be displayed in the "Buying Orders" column. Your order will be only executed when other traders want to sell the share at your buying price.

How to sell a share: If you want to sell a share, you also have two ways to do this:

1. When there are buy orders in the "Buying Orders" column that you want to sell, you can directly click on the listed order price at which you want to sell and press the "Sell" button, and then the share will be immediately sold.

2. You can enter a price that you are willing to sell in the field above the red button of "submit SELL order", and click the red button("submit SELL order"). Your sell order will then be displayed in the "Selling Orders" column. Your order will be only executed when other traders want to buy the share at your selling price.

Measuring ambiguity attitudes (shown on screen)

Screen 1

In this part, we present you a decision table with 11 situations. Each situation offers you a choice between drawing a ball from two different urns, urn 1 or urn 2. Both urns contain 10 balls, either black or white.

As explained before, both urns contain 10 balls, either white or black:

Urn 1: The composition of urn 1 changes from one situation to the next. While the number of balls in one color (e.g., white) increases from 0 to 10, the number of balls of the other color (e.g., black) decreases accordingly.

Urn 2: The composition of urn 2 is identical in each situation. However, you don not know how many balls are white and how many balls are black. Any combination is possible. There might be anywhere from 0 to 10 white balls, with the remaining balls being black.

One ball will be drawn from the urn you choose. The payment you can earn depends on the color of the ball drawn. Only one color yields payment. You can choose whether the color that yields payment is white or black. Please choose the color of the ball that provides you payment:

Please choose the color of the ball that provides you payment:

[X] White

[X] Black

Screen 2

Please take a look at the table below. In each of the 11 situations we would like you to indicate which urn (urn 1 or urn 2) you prefer drawing a ball from. At the end of this part, the computer will randomly select one out of the 11 situations. Then, depending on whether you have chose urn 1 or urn 2 in that situation, the computer will randomly draw one ball from that urn. Depending on the color of the ball, you earn the payment indicated in the table. Both urns contain 10 balls, either white or black.

As explained before, both urns contain 10 balls, either white or black:

Urn 1: The composition changes from one situation to the next

Urn 2: The composition of urn 2 is identical in each situation.

However, you do not know how many balls are white and how many balls are black. Any combination is possible.

Please note that the color of the ball you have chosen for payment is: [insert color]

Now please choose in each situation, from which urn you prefer to draw a ball, urn 1 or urn 2 ?

Appendix B. Additional information relating to observation 4

Another potential reason for the inconsistency between individual trading and aggregate market prices might be related to a mismatch in what the informed traders would like to achieve with their trades and what the non-informed traders

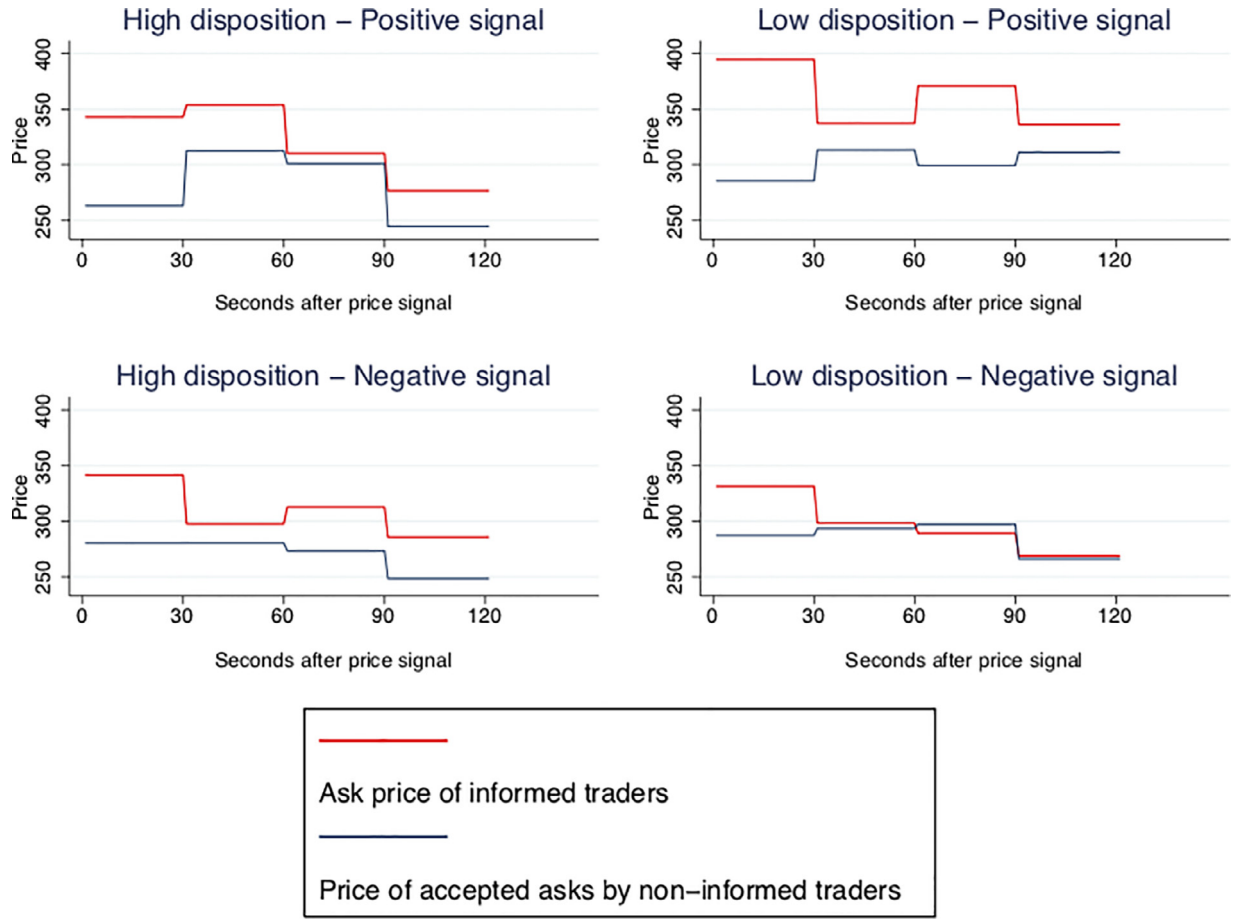


Fig. B.1. Asks made by informed traders vs. asks accepted by non-informed traders.

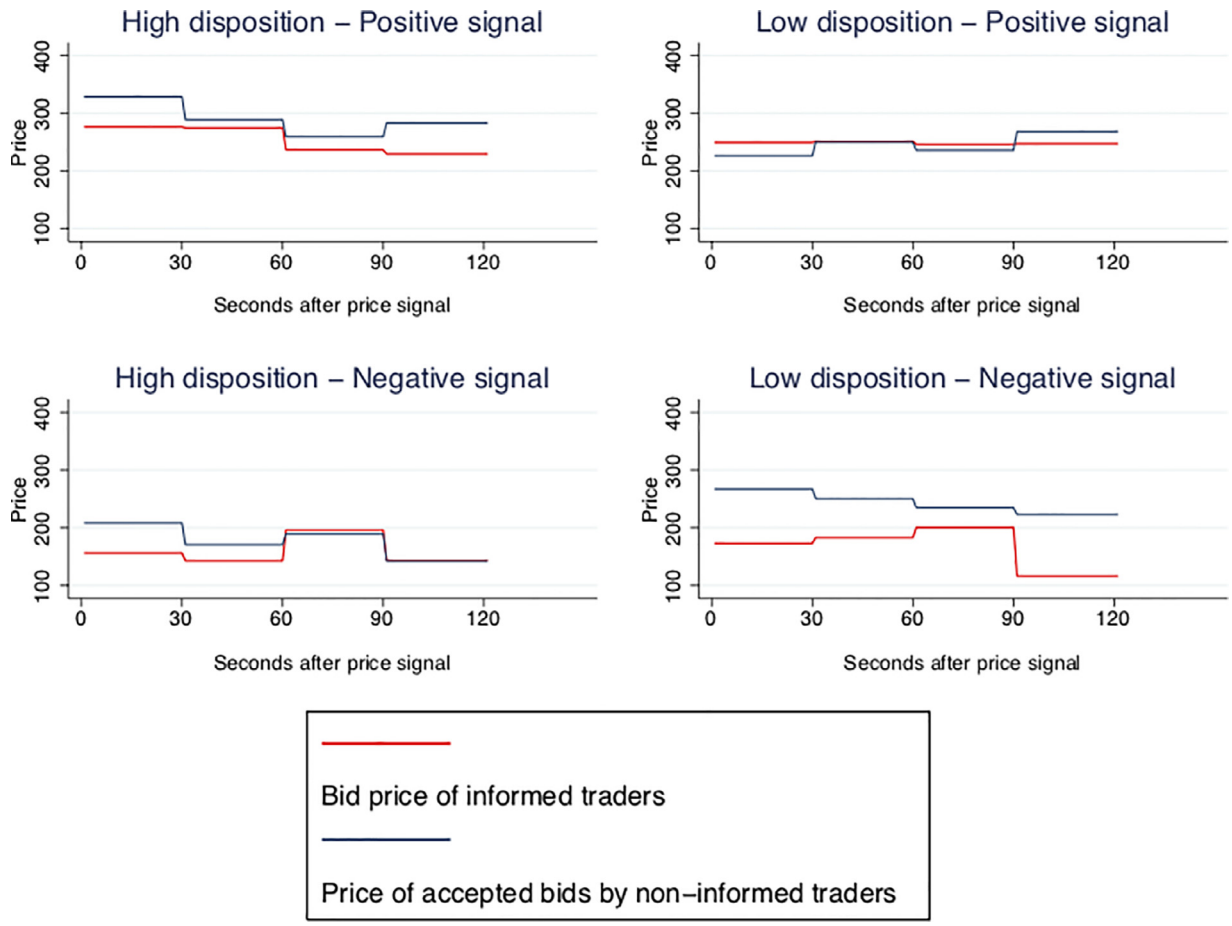


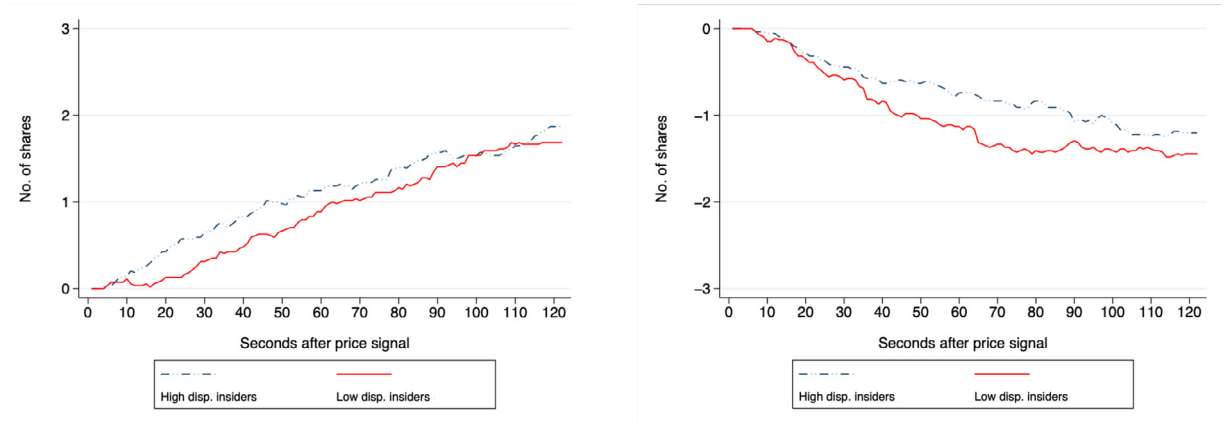
Fig. B.2. Bids made by informed traders vs. bids accepted by non-informed traders.

are willing to offer them. This mismatch is especially interesting in two cases; firstly, in the case of a positive price signal given to low disposition insiders and secondly in the case of a negative signal given to low disposition insiders. In both these cases the market price would be expected to respond to the signal relatively strongly compared to the case when the signals would be given to the high disposition insiders as low disposition insiders do not have the tendency to suppress the signal by contrarian trading behavior the way high disposition informed traders would (i.e. selling after a positive signal and holding the asset following a negative shock).

To further study these two cases, we compare the asks/bids made by informed traders (red line) with asks/bids accepted by non-informed traders (blue line) for the different disposition traders/signal combinations in Fig. B.1 and Fig. B.2. The first case of interest (Low disposition - Positive signal) relates to the top right panel in both figures. What is clear from this panel in Fig. 2 is that the asks made by insiders are rather high. However, on average these asks were not accepted by non-informed traders.

In the top left panel of Fig. B.1 (High disposition-Positive signal), we observe rather high asks in the starting period as well but here the informed traders lower their asks over time towards what the non-informed traders are willing to pay whereas this does not happen to the same extent for the low disposition informed traders. In Fig. B.2, we do not see a large mismatch in the two top panels when it comes to bids made and accepted by informed and non-informed traders respectively. However, the bid price is relatively low meaning that these bids do not move the transaction price up. It thus seems that only through asks the signal could come through. However, the informed traders in this market make 2.85 more bids than asks thereby reducing the relative impact of the asks that carry more information concerning the new fundamental value.

The second interesting case is that of the market with low disposition insiders following a negative shock (Low disposition-Negative signal), which relates to the bottom right panel in both Figs. B.1 and B.2. As was the case with the top right panel, here too one would expect a strong reaction in market prices following the (in this case) negative signal as there is more selling pressure than in the market with high disposition informed traders following a negative price signal (see Table 4). However, the bottom right panel of Fig. B.2 (Low disposition-Negative signal) shows that the bid prices of



(a) After a positive signal (b) After a negative signal

Fig. C.1. Average post-signal share build-ups (mismatched).

Table C.1
The trading behavior of informed traders (when mismatched).

Type of signal	The percentage differences between informed traders of high and low disposition effect levels in the volume of					
	Bids	Asks	Accepted bids	Accepted asks	Bought	Sold
A positive signal	−24.51***	43.86**	−49.12***	12.12	−9.69	−27.62**
A negative signal	−32.65**	−33.63***	48.64**	0.00	−5.75	−10.91

Notes: This table shows the percentage differences in the trading behavior between informed traders of high and low disposition effect levels in the markets where the sign of the signal does not match the domain in which the disposition effect levels of the informed traders are measured. Wilcoxon rank-sum test for significance (final row only): *** stands for $p < 0.01$, ** stands for $p < 0.05$, * stands for $p < 0.1$.

low disposition informed traders are much lower on average than what the non-informed traders are willing to sell for. Due to this mismatch, prices will not go down to the level to which the informed traders would like to see it go down, thereby explaining the rather small change in prices in this market (although larger in absolute terms than the change in market prices following a positive shock). Moving to the corresponding panel of Fig. B.1 (Low disposition-Negative signal), we observe a much smaller mismatch but the asks that are met by the non-informed traders are at relatively high prices, meaning that the average transaction price does not decrease by much. Moreover, and analogous to the case of the "Low disposition-Positive signal" market, the amount of relatively low-priced bids is 2.9 times lower than the amount of relatively high-priced asks placed. This thus means that the negative price signal as captured by the low bids is overshadowed by the higher priced as well as more numerous asks.

Summarizing, for the "Low disposition-Positive signal" market, we see that the information rich asks are on average not accepted and overshadowed by the more numerous and lower priced bids. For the "Low disposition-Negative signal" market, we see that the information rich bids are on average not accepted and overshadowed by the more numerous and higher priced asks.

The large difference between bids and asks and the accepted bids and asks when these bids and asks are informative of the price signal coupled with the higher frequency of non-informative bids/asks might thus potentially explain why in the above to mentioned cases of interest there exists an inconsistency between individual trading and aggregate market prices.

Appendix C. Supporting evidence for Observation 5

Support for Observation 5a): Following a positive signal, as we can see from Table C.1, unlike markets in Section 3.2, the high disposition informed traders accept significantly fewer bids and sell significantly less than the low disposition informed traders.[16] Moreover, the high disposition informed traders accept more bids and buy more than the low disposition informed traders, although in both cases, the difference is not significant. Further differences can be found when we consider the proxies I_{B-A}^{sumbit} and I_{B-A}^{accept}. In Section 3.2, both proxies I_{B-A}^{sumbit} and I_{B-A}^{accept} suggest a stronger willingness to sell the asset for the high disposition informed traders than for the low disposition informed traders. This is not the case with the markets we consider here. While we do find a stronger willingness of the high disposition informed traders to sell the

[16] See Table D.9 in the appendix for the percentage differences in the trading behavior between informed traders of high and low disposition effect levels in each 30-second post-signal trading period when the sign of the signal does not match the domain that the disposition effect levels of the informed traders are measured.

Table C.2
Percentage differences of prices between markets of high and low disposition informed traders (when mismatched).

Type of signal	The percentage differences between informed traders of high and low disposition effect levels in					
	Bid price	Ask price	Accepted bid price	Accepted ask price	Buy price	Sell price
A positive signal	−16.16***	6.82	19.21**	4.32	5.83**	12.17*
A negative signal	4.14	−4.20	3.99	20.11***	13.19**	−2.04

Notes: This table shows the percentage differences of prices between markets of high and low disposition informed traders in the markets where the sign of the signal does not match the domain that the disposition effect levels of the informed traders are measured. Wilcoxon test for significance (final row only): *** stands for $p < 0.01$, ** stands for $p < 0.05$, * stands for $p < 0.1$.

Table C.3
Underreaction in markets of high and low disposition informed traders (when mismatched).

Type of signal	Markets	Post-signal trading block (30 s. each)				
		1	2	3	4	ALL
A positive signal	Markets of high disposition informed traders	13.06***	18.97***	16.83***	15.07***	16.14***
	Markets of low disposition informed traders	23.88***	22.31***	20.51***	23.42***	22.22***
	Difference between the two markets	−10.82**	−3.34	−3.68	−8.35**	−6.08***
A negative signal	Markets of high disposition informed traders	29.65***	25.82***	19.14***	22.10***	23.52***
	Markets of low disposition informed traders	34.37***	30.09***	11.25***	2.62	20.76***
	Difference between the two markets	−4.72	−4.27**	7.89	19.48**	2.76

Notes: This table shows the underreaction (in percentages) in markets of high and low disposition informed traders and the differences between the two in the markets where the sign of the signal does not match the domain in which the disposition effect levels of the informed traders are measured. Mann Whitney U test (first two rows) and Wilcoxon test (final row) for significance: *** stands for $p < 0.01$, ** stands for $p < 0.05$, * stands for $p < 0.1$.

asset following a positive signal than that of the low disposition informed traders when looking at I_{B-A}^{sumbit}, the opposite is observed when we use I_{B-A}^{accept}. Specifically, we find I_{B-A}^{sumbit} to equal 47.87 for the high disposition informed traders and 151.18 for the low disposition informed traders, while I_{B-A}^{sumbit} and I_{B-A}^{accept} equal 105.00 and 17.33, respectively, for the high and the low disposition informed traders. In contrast to markets in Section 3.2, the latter proxy thus does not provide clear evidence of a higher positive change in the willingness to hold shares between the low disposition informed traders and the high disposition informed traders following a positive private signal.

Following a negative signal, a comparison of Tables C.1 and 4 reveals that the large and significant positive differences in the number of accepted asks between the high and low disposition informed traders in the market of Section 3.2 has disappeared in the markets considered here. Moreover, unlike the markets examined in Section 3.2, in the current markets, the high disposition informed traders actually accept significantly more bids than the low disposition informed traders. When we consider the proxies I_{B-A}^{sumbit} and I_{B-A}^{accept}, similarly, we observe an inconsistency. The proxy I_{B-A}^{sumbit} gives a similar result as in the market of Section 3.2: I_{B-A}^{sumbit} equals −74.25 for the high disposition informed traders and −161.7 for the low disposition informed traders. For I_{B-A}^{accept}, however, we find the opposite: I_{B-A}^{accept} equals −24.82 for the high disposition informed traders and equals −6.10 for the low disposition informed traders.

Support for Observation 5b): The comparison of Fig. C.1 and Fig. 2 reveals a clear difference. While the markets of Section 3.2 show a clear difference between the high and low disposition informed traders in post-signal changes in share holdings, no such differences are visible in Fig. C.1.

Support for Observation 5c): Comparing Table 5 with Table C.2 shows that, while the vast majority of differences in the markets of Section 3.2 are in line with Hypothesis 1, the differences in the markets considered in this subsection are rather inconsistent.[17] Some measures even point to the wrong directions. For example, following a positive signal, all measures, with the exception of the difference in submitted bids, are positive, and following a negative signal, both the differences in the price of submitted asks and the price at which the informed traders sell their assets are negative.

Support for Observation 5d: Table C.3 shows the underreaction as well as the differences in underreaction between markets of the high and low disposition informed traders. Unlike the markets discussed in Section 3.2, following a positive signal, the underreaction is overall significantly higher in markets with the low disposition informed traders than those with the high disposition informed traders, while following a negative signal, there is no significant difference in underreaction.

Appendix D. Additional tables

[17] See Table D.10 in the appendix for the percentage differences of prices between markets of high and low disposition informed traders in each 30-second post-signal trading period when the sign of the signal does not match the domain that the disposition effect levels of the informed traders are measured.

Table D.1
Number of bids and asks placed per second.

		Bids				Asks			
		Before shock	After shock			Before shock	After shock		
			All	Insiders	Outsiders		All	Insiders	Outsiders
R1	0–30	0.249	0.174	0.249	0.138	0.372	0.273	0.201	0.312
	31–60	0.258	0.135	0.189	0.111	0.420	0.366	0.384	0.357
	61–90	0.186	0.171	0.171	0.171	0.327	0.300	0.261	0.318
	91–120	0.129	0.117	0.114	0.120	0.288	0.294	0.228	0.330
	ALL	0.207	0.150	0.180	0.135	0.351	0.309	0.270	0.330
R2	0–30	0.345	0.135	0.123	0.141	0.414	0.555	0.906	0.378
	31–60	0.231	0.168	0.111	0.198	0.417	0.570	0.816	0.444
	61–90	0.219	0.123	0.144	0.114	0.366	0.480	0.657	0.393
	91–120	0.177	0.138	0.156	0.129	0.387	0.435	0.667	0.318
	ALL	0.243	0.141	0.135	0.147	0.396	0.510	0.762	0.384
R3	0–30	0.402	0.195	0.105	0.243	0.492	0.462	0.618	0.387
	31–60	0.231	0.192	0.105	0.234	0.489	0.450	0.432	0.459
	61–90	0.207	0.186	0.084	0.237	0.477	0.513	0.549	0.495
	91–120	0.192	0.189	0.069	0.249	0.387	0.372	0.423	0.345
	ALL	0.258	0.192	0.090	0.240	0.462	0.450	0.507	0.423
R4	0–30	0.408	0.339	0.618	0.201	0.591	0.393	0.210	0.483
	31–60	0.270	0.288	0.507	0.180	0.381	0.414	0.171	0.534
	61–90	0.264	0.249	0.462	0.141	0.390	0.417	0.207	0.522
	91–120	0.210	0.213	0.396	0.120	0.318	0.291	0.108	0.384
	ALL	0.288	0.273	0.495	0.162	0.420	0.378	0.174	0.480
R5	0–30	0.387	0.258	0.240	0.267	0.564	0.522	0.906	0.330
	31–60	0.342	0.267	0.207	0.297	0.447	0.510	0.567	0.480
	61–90	0.288	0.228	0.168	0.258	0.336	0.381	0.507	0.318
	91–120	0.288	0.198	0.168	0.213	0.231	0.315	0.339	0.303
	ALL	0.327	0.237	0.195	0.258	0.396	0.432	0.579	0.357
R6	0–30	0.411	0.435	0.678	0.315	0.531	0.342	0.216	0.405
	31–60	0.258	0.360	0.594	0.243	0.384	0.297	0.168	0.360
	61–90	0.303	0.381	0.606	0.270	0.351	0.234	0.138	0.282
	91–120	0.186	0.306	0.366	0.279	0.288	0.189	0.099	0.231
	ALL	0.291	0.372	0.561	0.276	0.390	0.267	0.156	0.321
R7	0–30	0.486	0.423	0.639	0.318	0.540	0.420	0.399	0.429
	31–60	0.474	0.264	0.339	0.225	0.393	0.279	0.189	0.321
	61–90	0.339	0.303	0.315	0.294	0.300	0.234	0.138	0.282
	91–120	0.198	0.357	0.390	0.342	0.153	0.207	0.171	0.225
	ALL	0.375	0.336	0.420	0.294	0.348	0.285	0.225	0.315
R8	0–30	0.447	0.339	0.183	0.417	0.531	0.561	0.723	0.480
	31–60	0.381	0.381	0.243	0.450	0.369	0.483	0.621	0.414
	61–90	0.321	0.216	0.150	0.249	0.294	0.414	0.579	0.333
	91–120	0.270	0.216	0.225	0.216	0.264	0.330	0.417	0.285
	ALL	0.354	0.288	0.201	0.333	0.366	0.447	0.585	0.378

Notes: Average number of submitted bids and submitted asks per second per round grouped over all pre- and post-shock traders with the latter group subdivided into informed trader and outsider traders. For sake of comparability all figures have been normalized to a nine-person market.

Table D.2
Number of accepted bids and asks per second.

		Accepted bids				Accepted asks				Trades	
		Before shock	After shock			Before shock	After shock			Before shock	After shock
			All	Insider	Outsider		All	Insider	Outsider		
R1	0–30	0.081	0.048	0.051	0.048	0.129	0.078	0.156	0.039	0.210	0.126
	31–60	0.108	0.057	0.027	0.072	0.147	0.108	0.150	0.087	0.255	0.165
	61–90	0.090	0.048	0.033	0.057	0.117	0.111	0.093	0.123	0.207	0.159
	91–120	0.042	0.039	0.048	0.033	0.087	0.123	0.129	0.120	0.129	0.162
	ALL	0.081	0.048	0.039	0.054	0.120	0.105	0.132	0.093	0.201	0.153
R2	0–30	0.072	0.033	0.039	0.03	0.123	0.123	0.039	0.168	0.195	0.156
	31–60	0.072	0.063	0.084	0.054	0.129	0.141	0.078	0.171	0.201	0.204
	61–90	0.063	0.045	0.039	0.051	0.162	0.138	0.132	0.141	0.225	0.183
	91–120	0.069	0.042	0.042	0.045	0.114	0.105	0.099	0.108	0.183	0.147
	ALL	0.069	0.045	0.051	0.045	0.132	0.126	0.087	0.147	0.201	0.174

(*continued on next page*)

Table D.2 (*continued*)

		Accepted bids				Accepted asks				Trades	
		Before shock	After shock			Before shock	After shock			Before shock	After shock
			All	Insider	Outsider		All	Insider	Outsider		
R3	0–30	0.120	0.042	0.072	0.024	0.108	0.081	0.057	0.093	0.228	0.123
	31–60	0.075	0.057	0.084	0.045	0.144	0.099	0.078	0.111	0.219	0.156
	61–90	0.072	0.063	0.084	0.054	0.162	0.117	0.123	0.114	0.234	0.180
	91–120	0.057	0.048	0.063	0.042	0.114	0.087	0.093	0.084	0.171	0.135
	ALL	0.081	0.054	0.075	0.042	0.132	0.096	0.087	0.102	0.213	0.150
R4	0–30	0.078	0.057	0.015	0.078	0.126	0.069	0.129	0.039	0.204	0.126
	31–60	0.099	0.099	0.018	0.138	0.129	0.114	0.201	0.069	0.228	0.213
	61–90	0.093	0.090	0.012	0.129	0.117	0.135	0.183	0.111	0.210	0.225
	91–120	0.081	0.084	0.051	0.099	0.111	0.105	0.168	0.072	0.192	0.189
	ALL	0.087	0.084	0.024	0.111	0.120	0.105	0.171	0.072	0.210	0.189
R5	0–30	0.087	0.057	0.078	0.048	0.159	0.072	0.033	0.093	0.246	0.129
	31–60	0.123	0.090	0.099	0.084	0.120	0.114	0.099	0.123	0.243	0.204
	61–90	0.093	0.081	0.105	0.069	0.123	0.120	0.123	0.120	0.216	0.201
	91–120	0.060	0.072	0.099	0.060	0.084	0.099	0.114	0.090	0.144	0.171
	ALL	0.090	0.075	0.096	0.066	0.123	0.102	0.093	0.108	0.213	0.177
R6	0–30	0.066	0.075	0.066	0.081	0.135	0.093	0.111	0.084	0.201	0.168
	31–60	0.087	0.084	0.093	0.081	0.096	0.105	0.177	0.066	0.183	0.189
	61–90	0.078	0.084	0.078	0.090	0.102	0.093	0.132	0.072	0.180	0.177
	91–120	0.060	0.069	0.072	0.066	0.096	0.081	0.120	0.063	0.156	0.150
	ALL	0.072	0.078	0.078	0.081	0.108	0.093	0.135	0.072	0.180	0.171
R7	0–30	0.087	0.063	0.027	0.081	0.114	0.105	0.168	0.072	0.201	0.168
	31–60	0.138	0.054	0.027	0.066	0.120	0.111	0.150	0.093	0.258	0.165
	61–90	0.057	0.054	0.027	0.066	0.108	0.105	0.162	0.075	0.165	0.159
	91–120	0.051	0.075	0.072	0.075	0.054	0.090	0.129	0.069	0.105	0.165
	ALL	0.084	0.063	0.039	0.072	0.099	0.102	0.153	0.078	0.183	0.165
R8	0–30	0.093	0.051	0.105	0.024	0.105	0.108	0.012	0.156	0.198	0.159
	31–60	0.117	0.084	0.177	0.039	0.099	0.135	0.060	0.171	0.216	0.219
	61–90	0.114	0.072	0.117	0.051	0.099	0.114	0.057	0.144	0.213	0.186
	91–120	0.087	0.075	0.129	0.048	0.090	0.108	0.063	0.132	0.177	0.183
	ALL	0.102	0.072	0.132	0.042	0.099	0.117	0.048	0.150	0.201	0.186

Notes: Average number of accepted bids, accepted asks and transactions per second per round grouped over all pre- and post-shock traders with the latter group subdivided into informed trader and outsider traders. For sake of comparability all figures have been normalized to a nine-person market.

Table D.3
Bid and ask prices.

		Bid				Ask			
		Before shock	After shock			Before shock	After shock		
			All	Insider	Outsider		All	Insider	Outsider
R1	0–30	235.46	271.78	298.93	243.98	375.29	394.57	352.94	407.95
	31–60	215.81	280.38	290.94	270.15	393.52	395.38	353.99	417.52
	61–90	259.92	265.48	288.30	253.13	357.31	361.25	328.88	374.29
	91–120	254.30	288.29	342.86	270.10	359.53	332.47	286.38	346.84
	ALL	238.23	273.37	296.31	256.61	373.22	373.33	335.92	388.35
R2	0–30	227.61	234.24	190.33	247.74	374.29	335.00	336.36	333.35
	31–60	250.60	252.40	241.00	254.40	353.04	328.20	315.76	339.63
	61–90	277.61	207.50	171.18	221.86	339.83	294.02	293.16	294.80
	91–120	276.65	191.21	168.75	199.76	342.33	259.28	255.98	262.74
	ALL	252.05	226.34	190.51	236.86	353.16	309.29	306.12	312.49
R3	0–30	260.77	241.55	183.47	255.84	374.01	343.06	323.99	358.50
	31–60	268.26	247.37	226.67	251.25	345.84	346.73	298.90	369.05
	61–90	270.83	253.34	208.93	263.88	317.12	297.09	267.79	313.01
	91–120	237.74	222.07	188.00	229.24	331.23	273.77	265.18	279.20
	ALL	260.64	242.73	200.46	252.17	343.11	317.98	291.15	333.91
R4	0–30	249.92	278.17	300.79	242.21	354.90	398.33	402.63	397.37
	31–60	262.67	281.68	297.70	256.84	365.55	339.91	350.32	338.22
	61–90	252.74	296.41	311.77	273.91	339.04	328.10	357.39	322.54
	91–120	246.82	268.00	266.43	270.04	334.32	310.89	345.00	306.11
	ALL	253.28	283.11	298.88	259.46	349.79	346.79	367.83	342.93

(*continued on next page*)

Table D.3 (*continued*)

		Bid				Ask			
		Before shock	After shock			Before shock	After shock		
			All	Insider	Outsider		All	Insider	Outsider
R5	0–30	245.74	213.60	210.76	214.63	362.93	350.25	348.01	353.29
	31–60	259.45	219.84	189.42	227.83	357.34	316.80	295.32	329.53
	61–90	255.38	226.70	206.28	232.33	351.90	294.97	313.04	281.92
	91–120	243.84	201.84	164.12	217.49	339.84	279.68	287.09	275.39
	ALL	251.43	218.23	196.42	224.98	355.74	315.86	319.50	312.93
R6	0–30	249.55	240.93	255.51	226.49	351.27	368.65	387.89	363.64
	31–60	263.61	277.45	283.08	270.81	329.92	384.05	374.60	386.23
	61–90	255.89	288.70	291.14	286.88	332.83	351.30	325.97	356.97
	91–120	253.10	298.28	304.87	293.97	333.65	357.49	333.33	363.84
	ALL	254.83	273.30	279.43	267.89	338.74	366.61	360.68	368.04
R7	0–30	254.72	218.40	198.55	238.85	366.28	385.03	396.76	379.62
	31–60	254.79	241.28	228.21	250.65	344.93	350.53	346.18	351.80
	61–90	234.85	257.92	247.14	266.87	332.73	370.82	416.59	356.93
	91–120	206.47	259.92	261.43	259.06	324.55	363.74	377.35	359.29
	ALL	243.74	241.32	226.68	253.25	348.69	370.28	389.17	363.54
R8	0–30	261.90	211.25	176.67	222.29	379.14	348.73	336.47	357.94
	31–60	252.89	227.94	179.27	242.72	355.97	316.12	297.94	329.79
	61–90	262.83	221.62	215.88	223.50	339.88	286.20	283.36	288.68
	91–120	227.85	207.02	208.00	206.70	326.20	298.89	263.13	322.24
	ALL	253.22	219.67	192.12	228.39	356.07	315.13	301.17	325.93

Notes: Average prices of submitted bids and submitted asks per round grouped over all pre- and post-shock traders with the latter group subdivided into informed trader and outsider traders.

Table D.4
Transaction prices.

		Accepted bids				Accepted asks				Trades	
		Before shock	After shock			Before shock	After shock			Before shock	After shock
			All	Insider	Outsider		All	Insider	Outsider		
R1	0–30	288.18	307.50	253.89	335.88	320.59	331.57	354.11	286.50	309.29	322.37
	31–60	233.60	309.81	232.00	327.50	321.75	323.97	336.00	313.81	288.34	319.52
	61–90	262.70	296.21	265.71	305.91	307.64	306.24	311.36	304.21	289.58	303.75
	91–120	218.50	269.33	247.50	294.29	296.55	268.33	310.00	240.00	273.25	268.60
	ALL	254.03	298.87	251.21	319.19	313.37	308.48	330.32	292.67	291.79	305.64
R2	0–30	236.61	281.80	279.57	283.75	317.77	293.26	245.71	298.90	288.94	291.14
	31–60	265.65	285.84	271.07	308.00	304.39	280.58	237.50	290.31	292.38	281.88
	61–90	277.61	236.61	261.50	222.78	301.86	242.42	197.77	260.02	295.90	241.07
	91–120	256.39	221.67	207.00	232.14	310.07	222.58	239.15	213.96	291.98	222.36
	ALL	257.40	258.23	261.43	255.47	308.08	262.65	221.60	274.26	292.37	261.64
R3	0–30	284.73	270.95	269.23	273.75	326.83	285.90	315.80	276.56	304.75	280.92
	31–60	275.73	263.73	278.40	243.73	318.34	276.98	282.00	275.35	305.55	272.62
	61–90	263.68	265.12	270.00	260.24	299.83	255.20	264.61	249.36	289.67	258.13
	91–120	253.63	271.19	283.33	263.90	303.95	260.75	262.38	260.10	289.74	264.55
	ALL	273.38	267.01	273.84	259.43	311.29	267.94	276.23	264.32	297.87	267.64
R4	0–30	266.05	309.60	425.00	293.86	295.32	293.11	303.76	277.14	284.75	299.98
	31–60	277.64	285.70	350.00	281.21	302.23	303.05	290.43	321.46	292.27	295.45
	61–90	268.61	276.72	258.75	279.60	291.46	296.04	288.26	302.88	281.82	288.57
	91–120	253.41	290.91	305.00	287.95	278.78	314.89	328.89	300.89	269.10	305.85
	ALL	267.20	286.99	311.94	283.64	292.41	300.63	298.20	303.33	282.50	295.12
R5	0–30	265.64	235.24	248.57	222.80	305.39	289.18	289.17	289.19	292.14	265.84
	31–60	264.49	244.17	286.11	212.71	289.59	265.52	228.22	280.77	276.95	256.89
	61–90	247.83	246.21	280.96	208.68	306.15	259.49	253.04	262.44	282.20	254.38
	91–120	222.38	213.59	230.91	196.27	291.82	246.05	232.06	257.38	262.96	234.15
	ALL	253.45	238.48	267.94	210.97	299.41	263.98	244.28	272.55	280.32	253.87
R6	0–30	242.73	270.34	246.92	280.03	309.28	309.73	280.26	328.40	287.29	291.79
	31–60	271.76	261.18	218.53	288.04	294.62	326.61	330.09	321.96	284.01	297.82
	61–90	260.10	281.37	238.76	298.21	296.93	325.32	317.65	333.00	281.36	304.72
	91–120	251.00	262.76	234.11	284.25	309.54	315.83	319.62	312.75	287.67	293.54
	ALL	257.50	270.94	233.53	289.48	303.15	320.53	314.72	326.01	285.08	298.16

(*continued on next page*)

Table D.4 (*continued*)

		Accepted bids				Accepted asks				Trades	
		Before shock	After shock			Before shock	After shock			Before shock	After shock
			All	Insider	Outsider		All	Insider	Outsider		
R7	0–30	283.65	295.76	272.00	300.00	305.08	356.44	323.10	393.62	295.89	333.68
	31–60	281.51	274.69	295.20	270.42	324.80	328.60	310.63	343.30	301.44	311.03
	61–90	251.16	272.17	277.73	270.13	318.11	344.27	342.42	345.90	294.52	319.22
	91–120	236.68	299.48	309.38	295.71	315.82	351.60	351.28	352.08	276.25	325.98
	ALL	270.01	284.62	288.48	283.53	315.90	344.04	330.97	356.88	294.75	321.88
R8	0–30	272.00	243.70	228.61	273.89	332.14	288.34	280.00	288.64	304.30	274.16
	31–60	282.37	250.67	254.03	243.00	327.44	285.04	292.36	283.74	303.35	271.76
	61–90	273.97	228.20	227.07	229.52	301.30	283.55	254.64	287.97	286.80	261.74
	91–120	276.11	203.78	193.50	218.73	295.77	251.32	228.80	258.58	286.04	232.44
	ALL	276.35	233.35	230.79	237.47	315.01	279.89	260.74	282.83	295.41	262.36

Notes: Average accepted bid prices, accepted ask prices and transaction prices per round grouped over all pre- and post-shock traders with the latter group subdivided into informed trader and outsider traders.

Table D.5
Percentage differences between informed traders and indicated groups in terms of the number of submitted/accepted bids.

		Informed traders vs.		
		pre-informed traders	pre-all traders	outsiders
R1	Bids	27.11**	−12.52	32.66**
	Asks	−11.24	−23.97**	−18.84**
	Accepted bids	−71.52***	−50.69***	−23.68**
	Accepted asks	−0.028	9.73	42.65**
R2	Bids	−56.02	−44.98***	−7.55
	Asks	105.76***	91.92***	98.93***
	Accepted bids	41.14	−27.57***	13.85
	Accepted asks	−27.87	−33.64***	−40.18***
R3	Bids	−54.86***	−65.06***	−62.50***
	Asks	24.48**	9.25	20.00**
	Accepted bids	−25.28**	−8.58	83.33
	Accepted asks	−40.12***	−33.42***	−12.33*
R4	Bids	27.87***	70.77***	208.85***
	Asks	−50.60***	−58.74***	−63.77***
	Accepted bids	−54.22**	−72.11***	−77.78***
	Accepted asks	49.98**	40.28**	131.76***
R5	Bids	−40.32***	−40.65***	−25.07***
	Asks	30.48***	45.32***	60.99***
	Accepted bids	−2.21	5.19	47.37**
	Accepted asks	−29.75**	−23.07**	−12.25
R6	Bids	133.90***	91.18***	101.98***
	Asks	−47.90***	−60.00***	−51.18***
	Accepted bids	−5.78	8.02	−0.80
	Accepted asks	66.42***	25.35**	90.38***
R7	Bids	85.14***	12.17	42.59***
	Asks	−44.67***	−35.79***	−28.23***
	Accepted bids	−48.64**	−52.85***	−45.28***
	Accepted asks	17.11	52.20***	98.21***
R8	Bids	−36.61***	−43.56***	−39.38***
	Asks	102.16***	58.84***	54.35***
	Accepted bids	33.62*	29.42**	228.13***
	Accepted asks	−3.57	−51.34***	−68.33***

Notes: Percentage differences between informed traders on the one hand and pre-shock informed traders, all pre-shock traders and post-shock outsiders on the other in terms of the average number of submitted/accepted bids and asks per second per trader. Wilcoxon test for significance: *** stands for $p < .01$, ** stands for $p < .05$, * stands for $p < .1$.

Table D.6
Percentage differences between informed traders and indicated groups in terms of the prices of submitted/accepted bids.

		Informed traders vs.		
		pre-informed traders	pre-all traders	outsiders
R1	Bids	28.40***	24.38***	15.47***
	Asks	−7.43***	39.41	−13.50***
	Accepted bids	2.06***	−1.11***	−21.30
	Accepted asks	−2.67	5.41***	12.86
R2	Bids	−23.06***	−24.42***	−19.57***
	Asks	−13.58***	−13.32***	−2.04
	Accepted bids	−10.83**	1.57***	2.34
	Accepted asks	−19.01***	−28.07***	−19.20*
R3	Bids	−17.24***	−23.09**	−20.51***
	Asks	−6.31***	−15.14***	−12.81***
	Accepted bids	−3.30	0.17**	5.56
	Accepted asks	−14.50***	−11.26	4.50**
R4	Bids	12.61***	18.00***	15.19***
	Asks	9.27**	5.16***	7.26***
	Accepted bids	5.61*	16.74***	9.98**
	Accepted asks	9.76*	1.97	−1.69
R5	Bids	−17.23***	−21.88***	−12.69*
	Asks	−16.52***	−10.19***	2.10
	Accepted bids	−3.67	5.71***	27.00***
	Accepted asks	−12.96***	−18.41***	−10.37**
R6	Bids	12.76***	9.65***	4.31
	Asks	9.84***	6.48	−1.99***
	Accepted bids	5.38	−9.31**	−19.33***
	Accepted asks	2.07	3.82***	−3.46
R7	Bids	−13.48***	−7.00***	−10.49**
	Asks	7.43	11.61	7.05***
	Accepted bids	−6.26*	6.84***	1.75
	Accepted asks	8.22***	4.77	−7.26***
R8	Bids	0.43***	−24.13***	−15.88***
	Asks	−16.49***	−15.42***	−7.60**
	Accepted bids	−7.86	−16.49	−2.82
	Accepted asks	−18.83***	−17.23**	−7.81

Notes: Percentage differences between informed traders on the one hand and pre-shock informed traders, all pre-shock traders and post-shock outsiders on the other in terms of the average prices of submitted/accepted bids and asks. Wilcoxon test for significance: *** stands for $p < .01$,**stands for $p < .05$, *stands for $p < .1$.

Table D.7
Percentage differences in the trading behavior between informed traders of high and low disposition effect levels.

Type of signal	Seconds after the signal	The percentage differences between informed traders of high and low disposition effect levels in the volume of					
		Bids	Asks	Accepted bids	Accepted asks	Bought	Sold
	0–30	−59.46	−5.26	200.00	21.73	−2.13	90.91
A	31–60	−62.64	122.58	66.67	−25.00	−31.75	180.00
positive	61–90	−62.65	27.03	200.00	−48.48	−49.12	107.69
signal	91–120	−71.05	109.52	−10.00	−21.88	−48.21	68.74
	ALL	−63.43***	54.33***	61.11	−21.77	−34.08***	106.00***
	0–30	30.30	25.38	−26.32	200.00	40.00	−23.21
A	31–60	−15.90	−8.93	−43.75	63.63	44.44	−30.99
Negative	61–90	11.11	−12.50	−9.52	120.00	36.36	−30.36
signal	91–120	−25.58	−18.75	−24.00	83.33	29.16	−28.30
	ALL	−3.40	−1.17	−27.84*	94.29**	36.49**	−28.39**

Notes: Wilcoxon tests for significance are for the entire trading phase after the signal: *** stands for $p < 0.01$, **stands for $p < 0.05$, *stands for $p < 0.1$.

Table D.8
Percentage differences of prices between markets of high and low disposition informed traders.

Type of signal	Seconds after the signal	The percentage differences between informed traders of high and low disposition effect levels in					
		Bid price	Ask price	Accepted bid price	Accepted ask price	Buy price	Sell price
	0–30	−5.90	−14.74	−38.61	8.12	8.37	−31.17
A	31–60	−7.27	−3.88	−32.85	7.09	4.84	−24.10
positive	61–90	−11.39	−11.34	−3.97	0.87	2.42	−6.58
signal	91–120	16.77	−18.94	−20.60	−9.75	−7.94	−25.82
	ALL	−6.12	−11.86***	−21.13**	3.29	3.57**	−18.88**
	0–30	23.86	8.16	14.34	8.84	34.90	8.50
A	31–60	13.15	5.00	17.13	−12.89	−2.13	10.80
negative	61–90	3.91	14.90	26.67	6.04	15.39	10.52
signal	91–120	-9.26	14.04	23.58	8.34	5.19	16.48
	ALL	10.04	10.91***	20.35***	1.14	10.12**	11.06***

Notes: Wilcoxon test for significance (final row only): *** stands for $p < 0.01$, **stands for $p < 0.05$, * stands for $p < 0.1$.

Table D.9
Percentage differences in the trading behavior between informed traders of high and low disposition effect levels in the markets where the sign of the signal does not match the domain that the disposition effect levels of the informed traders are measured.

Type of signal	Seconds after the signal	The percentage differences between informed traders of high and low disposition effect levels in the volume of					
		Bids	Asks	Accepted bids	Accepted asks	Bought	Sold
	0–30	−5.73	84.62	−58.33	50.00	9.80	−22.22
A	31–60	−42.99	13.33	−70.59	−15.63	−27.58	−48.38
positive	61–90	−47.70	0.00	−64.29	20.83	−22.00	−28.00
signal	91–120	7.14	65.00	0.00	8.70	8.11	−4.55
	ALL	−24.51***	43.86**	−49.12***	12.12	−9.69	−27.62**
	0–30	−13.63	−31.90	85.71	42.86	41.67	−16.00
A	31–60	−5.00	−46.94	0.00	0.00	−22.72	−37.50
negative	61–90	−42.31	−16.10	114.28	−8.33	−21.88	2.22
signal	91–120	−56.67	−36.72	50.00	−5.26	9.52	31.82
	ALL	−32.65**	−33.63***	48.64**	0.00	−5.75	−10.91

Notes: Wilcoxon test for significance (final row only): *** stands for $p < 0.01$, **stands for $p < 0.05$, * stands for $p < 0.1$.

Table D.10
Percentage differences of prices between markets of high and low disposition informed traders in the markets where the sign of the signal does not match the domain that the disposition effect levels of the informed traders are measured.

Type of signal	Seconds after the signal	The percentage differences between informed traders of high and low disposition levels in					
		Bid price	Ask price	Accepted bid price	Accepted ask price	Buy price	Sell price
	0–30	−18.81	1.91	8.28	12.82	8.03	5.83
A	31–60	−16.62	−6.81	28.37	−5.25	−2.11	14.10
positive	61–90	−13.04	23.96	13.32	6.60	8.71	9.63
signal	91–120	−12.38	11.35	26.32	8.43	9.27	19.96
	ALL	−16.16***	6.82	19.21**	4.32	5.83**	12.17*
	0–30	−2.86	−3.20	−3.14	23.70	6.40	−2.72
A	31–60	−4.92	−4.61	2.28	15.48	3.16	−5.94
negative	61–90	17.07	−7.39	2.73	26.98	24.58	−3.19
signal	91–120	8.80	3.01	29.70	8.03	9.15	22.79
	ALL	4.14	−4.20	3.99	20.11***	13.19**	−2.04

Notes: Wilcoxon test for significance (final row only): *** stands for $p < 0.01$, ** stands for $p < 0.05$, * stands for $p < 0.1$.

Table D.11
The disposition effect level distributions.

Disposition effect levels	0	1	2	3	4
Gain domain (%)	29.01	12.96	29.01	20.37	8.64
Loss domain (%)	8.02	3.09	10.49	8.64	69.75

Notes: The higher a disposition effect level in the gain (loss) domain is, the sooner (later) the subject stops playing in the four-gains series (the four-losses series, respectively), and thus the higher his/her disposition effect level is.

Table D.12
Ex-post disposition measure.

	Gain domain		Loss domain	
	Pos. signal	Neg. signal	Pos. signal	Neg. signal
High DP	0.16	−0.39	0.33	−0.38
Low DP	0.65	−0.36	0.36	−0.63

Notes: The ex-post measure is calculated by subtracting the proportion of losses realized (PLR) from the proportion of gains realized (PGR), see Odean (1998). The reference price used in calculating the measure is based on the weighted average purchase price of the shares. Portfolio updates after a sale are based in the last in first out (LIFO) principle meaning that when a share is sold, we assume the price of this share to be that of the latest share bought.

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